instruction manual

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DIGITAL VOLTMETER

MODEL 451

non-linear systems, inc.
SAN DIEGO COUNTY AIRPORT,
DEL MAR, CALIFORNIA

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OPERATION AND SERVICE MANUAL

FOR

DIGITAL VOLTMETER

MODEL 451

SERIAL NO. 11.1876

NON-LINEAR SYSTEMS INC.
DEL MAR, CALIFORNIA

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SECTION II

GENERAL INFORMATION

2-1 DESCRIPTION.

GENERAL: NLS digital instruments measure voltages and/or voltage ratios or electrical resistance (See Section 1, Specifications) rapidly and with a high degree of accuracy, and present the measured value directly in numerical form on a self-illuminated digital readout. Digital voltmeters are, essentially, self-balancing potentiometers. Digital ohmmeters are, essentially, self-balancing Wheatstone bridges. On standard models, range changing and polarity indication are automatic, except for the AC voltage ranges, and decimal point and polarity sign are automatically displayed (See Section 1, Specifications). These instruments are useful as general purpose laboratory, production, and field test instruments, and are adaptable for use as components of larger testing systems. The advantages of these digital instruments are:

*** High Speed.

*** Their accuracy approaches that of laboratory type equipment while their ruggedness permits use under conditions in which most laboratory type equipment would not operate.

*** Wide measuring range in multi-range models.

*** Numerical readings and automatic range changing and polarity indication features permit error free readings even with untrained personnel, and prevent instrument burn-out which results in other types of instruments when the range switch is ignored.

*** High input impedance at balance minimizes loading of the circuit being measured.

*** High resolution.

*** Ability to operate data recorders.

*** Ability to operate digital readouts at remote locations.

*** Ability to operate alarms, go-no-go indicators, etc.

*** Stepping switch life extended greatly by the exclusive NLS Stepping Switch Oil Bath.

CONSTRUCTION: Maximum use is made of etched copper circuitry on epoxy fiberglass boards. Solder-plating increases etched circuit and soldered connection reliability. Both sides of all circuit boards are easily accessible. All major circuitry sections within the instrument are connected together with wiring harnesses and plug-in connectors, and are easily removed from the instrument's main structure.

STEPPING SWITCH OPERATED CIRCUITS: The precision wire-wound resistors are mounted on solder plated etched circuits on high quality epoxy-fiberglass boards; and are connected to the stepping switches by a wiring harness which connects to the stepping switches by means of AMP taper tabs. This construction isolates the resistors from stepping switch direct shock and vibration and eliminates the need for touching a hot soldering iron to the resistors once they have been soldered into the circuit at the factory; thereby ensuring maintained accuracy after long use and maintenance operations, if any, on the switches themselves. The AMP taper tabs are easily removed and replaced while supplying adequate electrical connections (their use has been approved by the armed services), and are, in this application, more reliable than soldered connections. The resistors themselves are annealed after winding, moulded into epoxy resin, and then subjected to multiple hot and cold cycling to ensure long-term stability. Removal of four bolts permits folding the entire stepping switch assembly away from its etched circuit board to afford easy access to all wiring.

STEPPING SWITCHES: The stepping switches were designed for this specific application after extensive tests by NLS and the manufacturer. The unusual digital logic designed by NLS eliminates the need for off-normal and interrupter contacts on the stepping switches. This is very important since such contacts require periodic adjustment, fail during use, and shorten the life of the thyratrons which drive the stepping switch coil since the added friction and spring forces demand more stepping switch coil current.

The stepping switches used have the following features:

*** Extremely sturdy driving pawl and tool steel ratchet prevents fatigue failure and reduces wear.

*** Each deck on the switch is a moulded assembly to keep contacts in permanent alignment. Each individual deck can be easily replaced if necessary.

*** Diallyl phthalate insulation is used to ensure extremely high and constant electrical leakage resistance.

*** Molded coil bobbin construction is used to insure complete rigidity and long insulation life.

*** The exceptionally rugged armature return stop cannot wear out during life of the switch.

*** These switches can be adjusted with ordinary socket wrenches.

SECTION III

OPERATING INSTRUCTIONS

3-1. PRIMARY POWER: The standard instruments are designed to operate from 105 to 130 volts, 60 cps power sources. Some special instruments have been designed for operation from 220 volt lines and some for operation from 50 cps sources, (See Section 1, Specifications). Primary power requirements for standard instruments are satisfied by most nominal 115 volt 60 cps power lines. However, adverse operation of digital measuring equipment, as well as many other types of electronic equipment, can be caused by abnormal power line characteristics, such as low or high voltage; large transient changes; large amount of amplitude modulation; high voltage "spikes" generated by some types of welding equipment, and thyratron controlled machine tools, etc.; and large amounts of harmonic distortion, particularly third harmonic. The outputs of many types of line voltage regulators are very rich in third harmonic content. This can cause unstable operation and apparent loss of resolution in the digital instrument. Operation from such voltage regulators is, therefore, not recommended.

3-2. FRONT PANEL CONTROLS.

PRIMARY POWER: Primary power is turned on by the front panel power switch. This switch also has a STANDBY position to permit keeping the instrument warmed up but the stepping switches turned off to reduce needless operation of the stepping switches. It also permits "locking" the reading at any point in time. After turning the power switch on, there is an operation delay of 15 to 30 seconds, controlled by a thermal timer, to keep the thyratron plate power off until filaments have become heated.

DATA RECORDER MODE SWITCH: In instruments which are designed to operate data recording devices (See Section 1, Specifications) the modes of recorder operation are selected by additional positions on the primary power switch:

AUTO PRINT: One recording will be made each time the input signal changes value.

CONTINUOUS PRINT: Recording occurs at a cyclic rate as long as the digital instrument remains balanced.

NORMAL: Recording does not occur; digital instrument behaves as though recorder is not present.

MANUAL: When the digital instrument is balanced, one recording is made; and the reading remains locked, despite input signal changes, until the mode switch is moved back to NORMAL. This position can also be used for locking the digital instrument reading when desired.

AC VOLTAGE RANGE SWITCH: This switch is present only on AC-DC digital voltmeters. Keep this switch at its DC position for measuring DC voltages. Manually select the proper AC voltage range when measuring AC voltages.

3-3. CONNECTING THE INSTRUMENT.

A. DIGITAL VOLTMETERS FOR MEASURING ABSOLUTE DC VOLTAGE.
CONNECTING THE INPUT SIGNAL: Connect the signal to be measured to the terminal strip located behind a metal cover plate on the rear of the instrument.

TERMINAL NO.	CONNECTION
5	Signal "high" side
6	Signal ground
4	Shield ground

CAUTION: The signal ground terminal is connected to the instrument chassis ground, as is the case in most electronic measuring equipment. If a signal above ground potential is connected to the digital instrument input signal ground terminal, and if the digital instrument chassis is connected to the power ground of the equipment being tested with the digital instrument, then a short circuit will occur through the instrument, and can burn out the internal ground circuit wiring.

B. DIGITAL VOLTMETERS FOR MEASURING DC VOLTAGE RATIO (DIGITAL RATIOMETERS)
CONNECTING THE INPUT SIGNAL: Connect the input signal to the instrument as described in 3-3. A.

CONNECTING THE EXTERNAL REFERENCE VOLTAGE: An external DC reference voltage must be connected to digital voltmeters designed for measuring DC voltage ratios. Connect this reference voltage to the proper terminals on same terminal strip mentioned in 3-3. A. Reference voltage connections are listed below for those instruments where, in Section 1, Specifications, the reference voltage source is described as "External _____ volt DC source":

TERMINAL NO.	CONNECTION
1	Positive side external DC reference supply
2	Negative side of external DC reference supply
3	Ground terminal of external DC reference supply

CAUTION: Follow the above instructions carefully, and double check connections to the external reference supply. Improper connections can result in short circuiting the external reference supply.

NOTE: These instruments will also operate satisfactorily if a single polarity reference voltage supply (positive or negative with respect to ground) is used in place of a dual polarity reference voltage supply (positive and negative with respect to ground). However, in the former case, the only input signals that can be measured are those whose polarity is the same as the reference supply polarity,

all polarities referenced to instrument ground. See Section 4, Theory of Operation, Reference Voltage, for details regarding reference voltage source characteristics.

C. DIGITAL VOLTMETER FOR MEASURING DC AND AC VOLTAGES: The input signal terminal strip for these instruments is located behind a rectangular cover plate on the rear of the instrument's AC to DC converter. Connect the input signal, be it DC or AC, to the input terminals as listed below. The input terminals become connected to the AC to DC converter when the AC range switch is on AC voltage positions, and to the DC digital voltmeter section when the AC range switch is at the DC voltage position.

TERMINAL NO.	CONNECTION
5	Signal "high" side
6	Signal ground
4	Shield ground

CAUTION: The signal ground terminal for DC and AC signals is connected to the instrument chassis ground. Avoid damaging the instrument's ground circuitry; see the caution note in Section 3-3. A, above, under directions for connecting input signals to DC digital voltmeters.

D. DIGITAL OHMMETERS: Connect the resistance to be measured to the terminal strip located behind a rectangular metal cover plate on the rear of the instrument.

TERMINAL NO.	CONNECTION
6	One lead of the resistance (instrument signal ground)
5	Other lead of the resistance
4	Shield ground

CAUTION: Do not connect a voltage source into the ohmmeter terminals; such may damage the instrument.

E. SHIELDING AND GROUNDING: Adequate shielding and grounding are a must with high accuracy, high resolution, high input impedance instruments such as digital instruments. Personnel accustomed to making high precision measurements, particularly those in standards laboratories, are aware of the following necessities which should be observed when connecting digital instruments.

1. Shield both input leads. The lead connected to the digital instrument signal ground can act as an antenna and pick up stray noise, as can the input signal "high" side lead. The noise pick up problem increases, of course, when the impedance of the source being measured is high.

2. Ground the instrument signal ground lead. In some locations the AC power line receptacle ground or a water pipe ground may be adequate; while in other locations a better earth ground may be required. If trouble is encountered, a measure of the potential differences between various grounds is often very revealing. Because of the effects of poor grounding with electronic equipment in general, many laboratories and test locations have a good earth ground available.

3. Observe grounding precautions as required in most electronic instruments to prevent ground loops and their resultant bias and ripple effects.

4. With digital ohmmeters: Shield the resistance being measured to prevent electrical noise pickup. This is increasingly important the higher the value the resistance is. Shielding can be eliminated only if tests at the instrument and test resistance location establish that eliminating shielding does not result in inaccuracy, loss of resolution or unstable readout.

   Excessive electrical noise pick-up can cause one or a combination of the following: (1) Unstable readout; (2) A loss of resolution (i.e., the digital instrument will not respond to small changes in input signal); (3) A bias (i.e., offset) error in the readings. Please note that unstable readout of digital instruments can be caused by actual variation in input signal amplitude, which variations are often not detected with other types of instrumentation of lower resolution.

   Where excessive electrical noise is present at the digital instrument input terminals, external filtering of the signals may prove helpful. Note that the series resistance of an external filter can cause errors because of the voltage drop across the external filter series resistance. While this is true with any type of instrument, the high resolution of digital instruments makes it more evident.

3-4. PROCEDURE FOR STANDARDIZING: Digital voltmeters equipped with the manual type of standardization (See Section 1, Specifications) require occasional standardization; which is not required in instruments equipped with automatic standardization. To standardize manually standardized instrument:

A. Actuate the front panel CALIBRATE switch.

B. If the displayed reading does not agree with the value given on the front panel decal (which is marked "Calibrate to _____ Volts"), turn the shaft of the calibrate control (which is a slotted shaft ten turn control located behind the hole in the front panel) until the proper reading is displayed.

C. Release the CALIBRATE switch.

NOTES (1) The decimal point may appear in any location during the standardizing procedure because the DC voltage range change circuitry becomes de-energized during this operation. (2) This standardizing procedure standardizes the internal reference voltage supply against high accurate and stable standard cells.

3-5. CONNECTING THE REMOTE READOUT: If the digital instrument has connections for a remote readout (See Section 1, Specifications), plug the connector which is attached to the remote readout (if the remote readout was ordered complete with cable) into the receptacle provided for it at the rear of the digital instrument.

CAUTION: Tighten the connector locking screws evenly to prevent damaging the connector.

3-6. CONNECTING THE DATA RECORDER: Connections are provided to operate a specific type of data recorder when specified by the customer (See Section 1, Specifications). Instructions for connecting the data recorder are given in the data recorder section of this handbook.

3-7. COOLING: Do not subject the instrument to operating ambient temperatures in excess of 110°F. Do not subject the standard cells to temperatures in excess of 122°F.

3-8. LEVELING: No precaution needed unless instrument is mounted in a sloping panel rack. Under these conditions, the oil in the stepping switch oil bath reaches only the rearmost stepping switches. Ensure lubrication of frontmost switches by removing instrument from rack every 60 days and shaking it to cause oil to wash the frontmost switches thoroughly. If the stepping switch action is consistently slowed down after installing instrument in a sloping panel rack, and if holding instrument level eliminates this symptom, then drain about one half of the oil from the stepping switch oil bath.

SECTION IV

THEORY OF OPERATION

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SECTION IV

THEORY OF OPERATION

4-1. BLOCK DIAGRAM CIRCUIT DESCRIPTION: This section presents a brief description of theory of operation. More detailed information is presented in Section 4-2, Detailed Circuit Description.

A. FUNDAMENTALS: Non Linear Systems digital voltmeters are perhaps best described as "digital, self-balancing potentiometers," which in measuring the unknown input set up an equal or proportional voltage. It is well, therefore, to review some principles of potentiometers. Herein the term "potentiometer" shall apply to a system composed of a variable voltage divider, a reference voltage source and null detector, employed to measure voltages and/or voltage ratios by setting up a voltage equal to the input.

1. THE POTENTIOMETER PRINCIPLE: Consider the basic potentiometer circuit shown schematically in Figure 4-1. If an unknown voltage is applied, and the variable voltage divider adjusted until the voltage E_o is equal in magnitude to the unknown voltage, then zero current will flow through the galvanometer. This condition is called "balance," and no current is drawn from the input under the condition of exact balance. The unknown voltage can be computed from the formula:

$$\text{Unknown Voltage} = \frac{R_1}{R_1 + R_2} \times \text{Reference Voltage} = E_o$$

If the polarity of the input voltage is reversed then the reference voltage must also be reversed to obtain balance. The galvanometer pointer will now travel in an opposite direction (from previously) as the magnitude of the unknown voltage increases. It is this change in error signal sense which necessitates not only reversing the reference voltage, but also the error amplifier output lines in the digital voltmeter when input signal polarity is reversed.

2. MEASURING VOLTAGE RATIOS WITH THE POTENTIOMETER: When the potentiometer is balanced, the ratio of the unknown voltage to the reference voltage can be computed from the formula:

$$\frac{\text{Unknown Voltage}}{\text{Reference Voltage}} = \frac{R_1}{R_1 + R_2} \quad \text{(Refer to Figure 4-1)}$$

The potentiometer can be used to measure the ratio of unknown voltage to reference voltage if a graduated scale is attached to the variable voltage divider, and the scale read when balance is obtained. For the instrument to be accurate, the scale divisions must bear a definite relationship to the variable voltage divider resistance change, and the end points of the scale and the variable

voltage divider must coincide. If these conditions are satisfied, and if the scale is graduated from 0 to 1.0, the ratio of input voltage to reference voltage is measured by reading the scale when the variable voltage divider has been adjusted to obtain balance. If the scale is graduated from 0 to 100, then the input voltage can be interpreted in terms of "percent of reference voltage."

3. MEASURING ABSOLUTE VOLTAGES WITH THE POTENTIOMETER: To measure the absolute value of an unknown voltage, the reference voltage must be known. Instead of accurately measuring the reference voltage directly, it can be adjusted to the proper value if an accurately known voltage is available for use as a calibration reference. In this method, a standard cell of known voltage is connected in place of the unknown voltage (See Figure 4-2), the variable voltage divider dial reading set to this known voltage, and the voltage across the variable voltage divider adjusted by means of the rheostat R_c to obtain balance. The potentiometer is now "calibrated," or "standardized," and ready for use as an absolute voltage measuring device. This is analogous to the method employed in those models of Non-Linear Systems digital voltmeters which have the manual calibration feature.

   If the variable voltage divider dial is improperly set during this calibration procedure by a certain percent, say 1% of the standard cell voltage, then an error of 1% of the value read will be obtained over the entire range. Since dial resolution and galvanometer sensitivity have their limitations, it is important to use as high a known voltage as is practicable when "calibrating" a potentiometer to minimize these contributions to error.

B. DIGITAL VOLTMETER BASIC PRINCIPLE: As previously mentioned, NLS stepping switch type digital voltmeters are essentially self balancing digital potentiometers. Simplified schematics are shown in Figures 4-3 and 4-4. A stepping switch operated variable voltage divider, composed of wire wound resistors, divides a voltage, which is called the reference voltage, into a large number of precisely equal parts in the decimal number system. These particular stepping switches are called decade switches. An error amplifier compares this divided voltage, which is called the feedback voltage, with the input signal, and commands stepping switch motion in a logical sequence until the two voltages are equal within the limits of resolution of the instrument; whereupon stepping switch motion ceases, and the instrument is said to be at balance. Input to the error amplifier is through an electro-mechanical chopper. Automatic range and polarity changing features, where present, are accomplished by a range switch and a polarity switch. (See Figures 4-4 and 4-5).

There is a basic relationship between the number of steps (assuming equal steps) in the stepping switch operated variable voltage divider, the reference voltage amplitude, and error amplifier "gain" (error amplifier gain being defined as the smallest difference between unknown input voltage and feedback voltage which will produce a pulse output from the error amplifier):

$$\text{Amplifier gain} = \frac{\text{Reference voltage amplitude}}{\text{Number of steps in variable voltage divider}}$$

Using, as an example, a four digit instrument with a 10 volt reference:

$$\text{Amplifier gain} = \frac{10}{10{,}000} = 0.001 \text{ volts.}$$

If the reference voltage is increased or decreased, the error amplifier gain must be proportionately decreased or increased, respectively, if the instrument is to be returned to normal operating conditions. If error amplifier gain or reference voltage is too high, the instrument may oscillate; and if either is too low, the resolution of the instrument will tend to decrease. However, if amplifier gain is lower than nominal, the instrument will still increase its numerical display in steps of one digit in the rightmost window of the digital readout as the input signal is slowly increased. But if amplifier gain is lower than nominal, the digital instrument will decrease its numerical display by "X" digits (where "X" is two times the quantity obtained by dividing actual error amplifier gain by nominal error amplifier gain) if the input signal is slowly decreased.

For example, if amplifier gain is supposed to be 0.001 volt but is actually 0.002 volts, then the displayed reading would decrease by 4 digits each time it changes (e. g. 4.959, 4.955, 4.951, etc.) if the input voltage is being slowly decreased. This is because the error amplifier is kept operating over only 0.001 volt of its null region as we slowly increase the input voltage, but the error amplifier must go from one end of its null region, through zero, and then to the opposite end of its null region each time the numerical display decreases by one digit in the rightmost window.

In some digital instruments, error amplifier gain is intentionally reduced over portions of the instrument's range. This leads to decreased resolution over portions of the range. See Section 4-2 C. Error Amplifier, Automatic Gain Control.

C. REFERENCE VOLTAGE: The DC voltage impressed across the stepping switch operated Kelvin-Varley voltage divider is called the reference voltage. If absolute DC voltages are to be measured accurately, a precision DC reference voltage must be used. Unsaturated cadmium standard cells provide an extremely accurate and stable DC voltage, but are incapable

of supplying the amount of current required to energize the Kelvin-Varley voltage divider. Therefore, reference voltage power supplies which use standard cells as primary references have been developed. The type of reference voltage supplied in the instrument, or to be furnished externally to the instrument, is listed in Section 1, Specifications.

1. ZENER DIODE TYPE: In this type of internal reference voltage supply, matched zener diodes of equal and opposite temperature coefficients perform the final regulation of the DC reference voltage. DC power is supplied to the zener diodes by a transformer-rectifier-gas reference tube-type supply. This supply is highly stable, but exhibits a long term drift which is compensated for manually by actuating the front panel "CALIBRATE" switch, and adjusting the front panel "CALIBRATE" control (screwdriver slotted shaft), until the displayed reading agrees with the value given on the calibration voltage decal installed on the instrument's front panel (reference to Figures 4-2 and 4-4 may be helpful). This procedure standardizes the instrument by connecting internal, unsaturated cadmium standard cells to the error amplifier input; the "CALIBRATE" adjustment permits changing the reference voltage supply output to the proper value using the precise emf of the standard cells as a standard voltage reference. Standardization will need to be made only once every several hours when making routine measurements where highest accuracy is not important, but oftener when making measurements which exploit the instrument's accuracy capabilities.

2. AUTOMATICALLY STANDARDIZED TYPE: In digital voltmeters with automatic standardization, a highly stable, standard cell referenced, electronic, DC power supply, called the autocalibrator, automatically provides the proper reference voltage.

   An electronic comparator-regulator circuit in this power supply compares the power supply output voltage to the voltage of unsaturated cadmium standard cells at the rate of 60 times per second, in instruments operating from a 60 cycle per second AC power line, and acts to maintain the proper output voltage from the power supply, which is the reference voltage. Hence, the power supply output very closely duplicates the accuracy of the standard cells.

3. INSTRUMENTS FOR USE WITH EXTERNAL REFERENCE VOLTAGE: Thes instruments measure the ratio of the unknown input voltage to an external reference voltage. The polarity switch in instruments where, in Section 1, Specifications, the reference voltage is described as "External $\pm$ ____ volt supply," is wired as a selector switch which

selects the + supply when measuring positive inputs, and the - supply when measuring negative inputs (See Figure 4-5).

If your instrument was ordered for use with an "External + _____ volt supply" or an "External - _____ volt supply" reference, as determined from Section 1, Specifications, the polarity switch was probably set to its positive or negative position, respectively, at the factory and its electromagnet coil excitation lead removed. Check your circuit diagram to clarify this.

D. ERROR AMPLIFIER: The error amplifier acts as the null detector, or balance detector, in the digital instrument. It compares the feedback voltage and unknown input (appearing at the range unit output in multi-range instruments), and issues pulses to drive the stepping switches to adjust the feedback voltage and cause the instrument to reach an electrical balance. The error amplifier is phase sensitive, and issues these pulses on its "up" pulse or "down" pulse output line depending upon the amplitude and polarity relationships between the unknown input voltage and feedback voltage (See Figure 4-6).

E. DIGITAL LOGIC, OR SWITCHING LOGIC: Digital logic, or switching logic, means the predetermined sequence of switching operations which cause the digital instrument to attain an electrical balance. This switching sequence is determined by the way the "logic" levels on the stepping switches are connected in any one switch and between the switches. These "logic" levels are electrically isolated from all other switch levels. The inputs to the switching system logic levels are the "up" pulse and "down" pulse lines from the error amplifier. Each pulse applied to a stepping switch coil causes the switch to move one "step." Since the stepping switches are unidirectional in their motion, "up" pulses cause the switches to rotate in the same direction as "down" pulses; and the manner in which these "up" pulses and "down" pulses are routed from one stepping switch coil to another causes the switches to reach a position where the instrument is electrically balanced. A combination of "up" and "down" pulses are usually required to attain an electrical balance.

F. RANGE CHANGING: Automatic range changing in multi-range instruments is accomplished by a stepping switch operated input signal attenuator. This switch is pulsed by the error amplifier under two conditions: (1) when the instrument reaches full scale on a given range and if reading is lower than the input signal voltage; and (2) when a zero appears in the leftmost window of the readout and if the instrument is not on its lowest range.

G. POLARITY INDICATION: Instruments with automatic polarity indication (See Section 1, Specifications) automatically measure DC signals which are either positive or negative with respect to the instrument's signal

ground; and the proper polarity sign is displayed in the digital readout. The automatic polarity feature is achieved by the polarity stepping switch, which is pulsed by the error amplifier when the instrument displays all zeros during its balancing process, and if the error amplifier indicates that the reading of all zeros is still "off scale." When pulsed, the polarity stepping switch reverses the reference voltage; it also interchanges the "up" and "down" pulse lines from the error amplifier where they connect to the "digital logic" levels of the other stepping switches. The latter operation is required to retain proper sensing in the instrument (See Figure 4-6).

H. DIGITAL READOUT: The digital readout numerals and other symbols are engraved on plastic plates which are edge-lighted by incandescent lamps energized through an additional level on each stepping switch. These levels are electrically isolated from all other levels. Generally, only one remote digital readout can be wired in parallel with the readout in the instrument without exceeding the excitation transformer power rating.

I. DATA RECORDER OUTPUT: Some digital voltmeters are equipped with an output to operate a specific type of digital data recorder (See Section 1, Specifications). The "automatic print control" installed in such digital voltmeters automatically detects when the digital voltmeter is at a balance, and then issues a print command signal. A front panel selector switch controls the automatic print control to permit manual selection of any one of several modes of data recording. The "printer connection" brings out the contact closures from the "printer" levels on each stepping switch for operating the data recording system. The "printer" level on each stepping switch is electrically isolated from all other levels on that switch. In some special instruments, the stepping switch "printer" levels are used for operating devices other than data recorders, such as alarm circuits, go-no-go tolerance indicators, etc.

J. AC VOLTAGE MEASUREMENTS: In digital voltmeters with AC voltage ranges (See Section 1, Specifications), AC voltages are first converted to DC by the AC to DC Converter, and then this DC voltage is measured by the DC voltage measuring section of the digital voltmeter. The manually operated AC voltage range switch on the instrument's front panel governs AC voltage range selection, and controls decimal point display. Semiconductor diodes are used for converting the unknown AC input signal to a DC voltage in the AC to DC converter. The diode rectification characteristic is linearized and stabilized by a high gain electronic amplifier. The manual AC range switch operates an attenuator, which accurately divides down the unknown AC input signal before entering the remainder of the circuitry, to afford multi-range operation and to prevent overloading electronic circuitry in the AC to DC converter.

4-2. DETAILED CIRCUIT DESCRIPTION.

A. STEPPING SWITCH ASSEMBLY.

1. GENERAL: Incorporated in the stepping switch assembly are the range, polarity, and decade (feedback voltage generation) stepping switches, the range attenuator, and the feedback voltage generating precision resistors (Kelvin-Varley circuit). The assembly is mounted on an etched circuit board, and immersed in an oil bath. The oil bath greatly prolongs stepping switch life by providing continuous lubrication for the driving mechanism and electrical contacts; it also minimizes humidity problems. In some five digit instruments, the range stepping switch is mounted on the etched circuit board and is outside the oil bath. The range stepping switch is infrequently operated, and its life is adequate with occasional manual lubrication. See Section 5, Maintenance. In several special instances, the range and polarity switching functions have been performed by relays rather than stepping switches. In other cases, the range and polarity switching functions have both been performed by one stepping switch, rather than by two separate stepping switches. Consult your circuit diagram.

2. STEPPING SWITCHES: The switch consists of a bank of stationary contacts arranged semicircularly, and a bank of mating rotary contacts (wipers), which are rotated by a driving mechanism. The switches are unidirectional in motion. When the driving mechanism electromagnet is energized by a sufficiently high voltage, an armature, or clapper, is pulled toward the coil against the force of a helical spring. This same motion causes a pawl to move back one step along a ratchet mounted on the rotary contact bank shaft; this "cocks" the switch but does not advance the contacts. When the electromagnet is de-energized, the helical spring restores the armature to its original position, pushing the pawl assembly which is coupled to it. The pawl, in turn, rotates the ratchet and, therefore, advances the rotary contacts by one step.

   Off normal and interrupter contacts are eliminated from stepping switches in NLS instruments because of the unique type of digital switching logic employed. Multi-level ("multi-deck") stepping switches are necessary since one set of electrically isolated contacts are used for operating the digital readout, another for the data recorder (if one is used), several for the digital logic circuits, and several others for the potentiometric circuits (polarity reversal, range selection, and feedback voltage generation).

3. DEVELOPMENT OF FEEDBACK VOLTAGE: The feedback voltage is developed by a stepping switch operated Kelvin-Varley voltage divider which divides the reference voltage into a large number of equal increments. Figure 4-4 presents a circuit diagram of the Kelvin-Varley voltage divider circuit for a four digit instrument. Five digit instruments have a five decade Kelvin-Varley voltage divider, and three digit instruments have only three decades. Each decade is operated by an individual stepping switch. Such switches are called "decade switches". Herein, the least significant figure on the readout (rightmost window), the decade stepping switch, and Kelvin-Varley decade associated with it are referred to as "Decade 1." The other decades are numbered sequentially from right to left. (from the least significant to the most significant figure). Each decade is capable of dividing the voltage applied across it into ten equal parts (Figure 4-4 shows this in detail). Therefore, the reference voltage can be divided into 10x10x10x10, or 10,000, equal steps in a four digit instrument; into 10x10x10, or 1,000, equal steps in a three digit instrument; and into 10x10x10x10x10, or 100,000 equal steps in a five digit instrument. As an aid in understanding overall theory, it is repeated here that the nominal error amplifier gain should be such that an "up" or "down" pulse must be generated if the input and feedback voltages differ by an amount equal to one step of the Kelvin-Varley divider. The exception to this are instruments with automatic gain control; (See Section 4-2 C.).

One advantage of the Kelvin-Varley type divider is that the reference voltage can be divided into 10,000 equal parts using only 43 resistors (for a four digit instrument). Furthermore, the absolute accuracy of the resistors does not have to be $\pm$ 0.01% to achieve a linearity of $\pm$ 0.01% of full scale. The decade resistors associated with the most significant figure (leftmost readout window) are the most critical. These are matched at the factory for best overall accuracy; but the probability of achieving 0.01% linearity, when a 0.05% resistor is used as a replacement for one which has failed, is extremely favorable. The resistors of the second most significant figure decade are only one-tenth as critical as those in the most significant figure decade (leftmost readout window), etc., until, in the least significant decade, inaccurate (say 10% tolerance) resistors can be used without appreciable effect upon instrument linearity. However, highly accurate, stable, aged, wire-wound resistors are used in all decades to reduce somewhat the relatively stringent accuracy requirements of the two most significant decades, and to produce an instrument of overall high quality. Another Kelvin-Varley circuit advantage is that the effect of stepping switch contact resistance upon linearity decreases the farther we progress from the most significant figure decade (leftmost window). The Kelvin-Varley voltage divider is, in a sense, self-checking as described in Section 5, Maintenance.

B. DIGITAL LOGIC: An understanding of the basic digital logic is not necessary for understanding most aspects of the digital voltmeter, but is very valuable. After the digital logic is understood, the operations involved in attaining a balance when the input voltage is changed to a new value can be worked out with the aid of a digital voltmeter circuit diagram or a pulse circuit schematic. Two facts should be remembered when working out digital voltmeter operations:

*** The error amplifier generates pulses on its "up" pulse line whenever the feedback voltage is less positive than the unknown input voltage, and generates pulses on its "down" pulse line for the opposite condition. If the unknown input voltage is negative with respect to ground, these pulses are interchanged by the polarity switch before entering the rest of the digital logic circuitry. If the input voltage is positive, these pulses will pass directly through the polarity switch to the digital logic circuitry without being interchanged.

*** The stepping switches are unidirectional in operation; therefore, "up" and "down" pulses always move the wipers in the same direction. The manner in which "up" and "down" pulses are routed through the polarity, range, and numerical decade stepping switches permits attaining balance and decides upon the sequence of operations in doing so. In attaining balance, the digital voltmeter's switching operations proceed in a logical sequence toward balance in a manner which requires both "up" and "down" pulses.

1. POLARITY SWITCH: "Up" and "down" pulses are first routed from the power amplifier through the polarity switch. If the polarity switch is initially in the proper position for attaining balance with the input voltage positive, and if all decades are driven to zero, and if the "range decade" stepping switch is in the "decimal point leftmost" position, and if "down" pulses are still present, this indicates that the input voltage is now negative. Pulse routing is such that, under these conditions, the "down" pulses are routed to the polarity stepping switch coil and step it until the polarity switch is driven to the "reversed" position, thereby reversing the "up" and "down" pulse lines to the rest of the stepping switches and also reversing the polarity of the reference voltage as applied to the digital voltage divider. If the polarity switch is inially in the proper position for attaining balance with the input voltage negative, then "up" pulses will cause polarity switch reversal, if "up" pulses are still present when all decases are driven to zero, and if the "range decade" stepping switch is in the "decimal point leftmost" position.

2. UP PULSE ROUTING: Assuming that the input signal is positive, "up" pulses leaving the polarity switch are connected to the first decade (rightmost digit) stepping switch wiper and, through the switch contacts, will step it once per pulse. If balance is not attained within that decade, and the decade is driven to nine, the "up" pulses are transferred to the next numerical decade, and so forth, until all decades are driven to nine. Subsequently, "up" pulses are transferred to the "range decade" stepping switch. If the range decade is at any position other than the "decimal point rightmost" position, its coil is pulsed, causing a shift in decimal point, and hence a factor of ten change in the input (or "range") attenuator. If "up" pulses are still present, the range decade stepping switch is pulsed again and the decimal point is again shifted, until the proper range is selected. Thus, if the input voltage exceeds the highest digital voltmeter reading possible, all decades go to nine, the decimal point is shifted to the rightmost position and stepping switch action ceases, although "up" pulses are still present at the amplifier output terminals.

3. DOWN PULSE ROUTING: "Down" pulses are routed through the stepping switches on a switch deck electrically isolated from all other wipers and decks. They enter through the polarity switch, as do the "up" pulses.

   "Down" pulses transfer from one stepping switch coil to another when a stepping switch reaches its "0" contact. However, if the instrument reading decreases to a "one" in the leftmost window of the readout and zero in all other windows, (that is, it reaches 10% of full scale), the "down" pulse is transferred to the range decade stepping switch to select a more sensitive range for the instrument by switching the range unit voltage divider. An auxiliary circuit prevents this sequence if the instrument is already on its lowest range.

   Shown on the following page are two examples of pulse operation in a four digit instrument. The designation "up" pulse or "down" pulse refers to the type of pulse generated when the associated numerical reading occurs.

(a) Unknown voltage changes from +4.538 to +4.542

4	5	3	8	
4	5	3	9	"Up" pulses
4	5	4	9	"Down" pulse
4	5	4	0	
4	5	4	0	
4	5	4	1	"Up" pulses
4	5	4	2	digital instrument at balance

(b) Unknown voltage changes from +0.010 to +0.009 volts

0	0	1	0	
0	0	2	0	
0	0	3	0	
0	0	4	0	
0	0	5	0	"Down" pulses
0	0	6	0	
0	0	7	0	
0	0	8	0	
0	0	9	0	
0	0	0	0	
0	0	0	1	
0	0	0	2	
0	0	0	3	
0	0	0	4	"Up" pulses
0	0	0	5	
0	0	0	6	
0	0	0	7	
0	0	0	8	
0	0	0	9	digital instrument at balance

C. ERROR AMPLIFIER: The error amplifier compares the feedback voltage and unknown DC voltage, which appears at the output of the range attenuator in multi-range instruments, and issues pulses to drive the stepping switches if the difference between the two voltages is sufficiently large. Phasing of the error amplifier chopper vibration and thyratron plate voltage, which is an AC voltage of power line frequency, is such that pulses appear on the error amplifier's "up" pulse line when the feedback voltage is less positive than the unknown DC voltage, and pulses appear on the "down" pulse line when the feedback voltage is more positive than the known DC voltage (See Figure 4-6). Note that the terms "less positive" and "more positive" apply regardless of whether the unknown and feedback voltages are positive or negative with respect to instrument signal ground. Remember, if the unknown DC voltage is negative with respect to instrument signal ground, the "up" pulse line and "down" pulse line are interchanged by the automatic polarity switch, in instruments having automatic polarity indication (See Section 1, Specifications), before the pulses reach the rest of the digital logic circuits; this is necessary to preserve proper sensing throughout the instrument.

A detailed explanation of error amplifier theory follows:

1. CHOPPER: The unknown DC voltage is applied to one stationary contact of an electromechanical chopper, and the feedback voltage is applied to the other stationary contact. The waveform at the chopper's vibrating contact is a square wave whose peak-to-peak amplitude is the difference between the unknown voltage and the feedback voltage. If the unknown voltage is less positive than the feedback voltage, this square wave will have a certain phase relationship to the power line sinusoid; and if the unknown voltage is more positive, the phase relationship of this square wave will change by 180 electrical degrees, (See Figure 4-6). If the unknown input and feedback voltages are equal, the square wave peak-to-peak amplitude is zero. The absolute voltage values of the square wave are, of course, the absolute values of the unknown voltage and the feedback voltage. However, absolute values of the waveform are of little consequence in understanding amplifier operation since the amplifier's first stage effectively discards it and passes only the square wave component to the rest of the amplifier. In most models, the chopper contacts have neon tubes or diodes across them to protect the contacts from overload.

2. CALIBRATE SWITCH AND RHEOSTAT: This is applicable only to instruments which measure absolute values of voltage, and have manual calibration, (See Section 1, Specifications). For calibrating the instrument, the calibrate switch permits inserting the known potential of a precise, unsaturated, cadmium standard cell into the amplifier input in place of the unknown input signal. THE CALIBRATE RHEOSTAT permits adjusting the reference voltage during the calibration procedure.

3. FIRST STAGE AMPLIFICATION: The first stage (labeled V_1 on all instruments except Model 350, which uses V_2 as the first stage) operates in the following manner: The chopper is connected to the grids of the first stage. If the grid connected to the chopper vibrating contact ("first grid") becomes more positive with respect to the associated cathode, then plate current flow in that tube section increases, and both cathodes become more positive. As a result, the second grid is now more negative with respect to its cathode; less plate current flows in that tube section; and the plate potential becomes more positive. Thus, the input signal has been amplified but its phase has not been inverted. The capacitor in the output plate of this stage removes the DC component from the square wave and, consequently, feeds the second stage of amplification an AC square wave.

   Model 350 has no "second stage" because further amplification is unnecessary before applying the signal to the phase splitter circuit formed by tubes V3A and V3B.

4. SECOND STAGE AMPLIFICATION: The second stage, (labeled V_2 except in Model 350, wherein V_2 acts as the first stage and V_1 is not present), operates essentially the same as the first stage, and further amplifies the signal without inverting its phase. The potentiometer in V_2 plate circuit permits adjusting error amplifier over-all gain, and is called the error amplifier gain control.

5. AUTOMATIC GAIN CONTROL: Refer to the error amplifier schematic. If connections labeled "AUTO GAIN" are present, then your instrument has automatic gain control. Five digit DC, and four or five digit AC, digital voltmeters generally have this feature. Automatic gain control maintains instrument stability in the following circumstances:

   (a) If the resolution of a digital instrument is greater than the instrument's linearity, then the instrument may be unstable over certain portions of the measuring range. This may be explained as follows: Consider the two Kelvin-Varley voltage divider taps whose voltages most closely bracket the value of the unknown input voltage: If the Kelvin-Varley voltage divider linearity is not better than the instrument's resolution, then the voltage on one of these two taps can be such that an "up" pulse will be generated when the stepping switch dwells there, and the voltage on the other tap can be such that a "down" pulse will be generated. Thus, the stepping switch can find no voltage divider tap within the error amplifier null region, and continually "hunts." This can occur particularly on five digit instruments where one digit resolution amounts to 0.001% of full scale; a Kelvin-Varley voltage divider's accuracy and long term stability of 0.001% of full scale is difficult to assure.

(b) If the reference voltage source stability in an absolute DC measuring digital voltmeter is not equal to or better than the instrument's resolution, then the readout display will change, the rate of change being dependent on the rate of change of reference voltage. In a five digit instrument operating at full resolution, a reference voltage change of 0.001% will result in a change of one digit in the readout display. The same symptom occurs if the unknown input changes by 0.001%, and very few DC voltage sources are that stable.

(c) AC voltages are rarely stable to 0.01%, but the resolution capability is 0.01% in a four digit instrument and 0.001% in a five digit instrument.

The automatic gain control maintains stable readout under the above conditions by decreasing error amplifier gain, and thereby decreasing instrument resolution, in steps proportional to how far toward full scale the instrument's reading is on each range. The intelligence for automatic gain control comes from a variable resistance, which is formed by resistors wired to the contacts of an additional deck on the stepping switches. The variable resistance is connected into the cathode circuit of V_2. Error amplifier gain decreases when the variable resistance is increased in value. Normal error amplifier gain can be achieved by reducing the variable resistance to zero. Sometime users have done this intentionally, by short circuiting or shunting the variable resistance, to gain more resolution; however, the instrument may not function satisfactorily under these circumstances.

In standard five digit instruments, the automatic gain control variable resistance is kept connected into V_2 cathode circuit at all times on DC voltage ranges; and a relay, which is actuated automatically when the instrument is put on AC ranges, connects in an additional variable resistance, which is similar to the one previously discussed, to provide additional automatic error amplifier gain reductions on AC ranges.

In standard four digit instruments, automatic gain control is not necessary on DC voltage ranges, but is connected in on AC ranges by a relay, in a manner similar to that described above for five digit instruments.

In standard three digit instruments, automatic gain control is unnecessary on either the DC or AC voltage ranges.

6. PHASE INVERTER STAGE - Tubes labeled V3A and V3B: The phase inverter stage converts the single waveform which is capacitively coupled to it from V_2 plate circuit, into two waveforms 180 electrical degrees out of phase with each other; this being required to generate two outputs ("up" pulse line and "down" pulse line) from the error amplifier. This stage operates as follows: Assume that the grid of V3A is driven more positive with respect to ground, V3A plate will thereby be driven more negative; hence, V3A output waveform is 180 electrical degrees out of phase with V3A grid waveform. V3A cathode potential becomes more positive; and, since V3A and V3B cathodes share a common cathode resistor, V3B cathode also becomes more positive. V3B grid is held at ground potential, and V3B cathode becoming more positive causes V3B plate potential to become more positive with respect to ground. Therefore, V3B plate waveform is in phase with V3A grid waveform.

7. THYRATRON DRIVER STAGE - Tubes labeled V4 and V5: This stage generates pulses, in response to signals from the phase inverter stage, to reliably drive the power stage thyratrons, (which furnish power pulses to operate the stepping switches) even in the presence of spurious noise signals, etc., of reasonable magnitude. The power thyratrons are located on the power supply chassis. The driver stage is unusual in that the input and output are on the same grid, which is the control grid, pin 1. Operation is as follows: The outputs of the phase inverter stage are capacitively coupled to the control grids, which are normally biased to cutoff by the resistive network connected to the B- supply. The grid voltage, at which the thyratrons fire, is essentially governed by the difference between the unknown input voltage and feedback voltage, the gain of preceeding stages, and the grid bias voltage. The shield grid, pin 5, is also a control element, and is used for speed control purposes which is explained later. The control grid bias is permanently set by fixed resistors, and the overall amplifier gain (minimum amplifier error voltage input which will cause pulses to be generated at the amplifier output) is adjusted by the gain control potentiometer in V2 plate circuit. Thyratron plate voltage is an AC voltage from the power supply transformer, so the thyratrons can fire only during the positive half cycle of plate voltage. Under these conditions, a thyratron can fire only if its control grid signal is in phase with the AC voltage plate voltage. When a thyratron fires, its two grids and cathode assume plate potential (which is positive); the neon tube (V7 or V8) in its control grid circuit fires; and a positive pulse is emitted on the associated amplifier output line ("up" pulse or "down" pulse line). The thyratrons extinguish on the next half cycle of power line waveform, since the plate potential then becomes negative. The neons, V7 and V8, afford

excellent electrical isolation between the driver thyratrons, V4 and V5, and the power thyratron grids of the next stage; the neons are biased negatively, and prevent any unwanted signals (spurious noise, etc.) on the driver thyratron grids from entering the power thyratron grids; also, when either driver thyratron, V4 or V5, fires, the other driver thyratron is blocked from firing because both driver thyratron cathodes become positive.

8. SPEED CONTROL CIRCUIT: Thus far, it would appear that the amplifier pulse output occurs at power line frequency. However, this is not desirable, and the speed control circuit is incorporated to block driver thyratron firing on alternate positive cycles of the power line; hence, the stepping switch pulsing rate is reduced to one half power line frequency. The speed control circuit operates by applying a negative potential to the driver thyratron (V4 and V5) shield grids, pin 5, on alternate cycles of the power line. The negative potential is obtained through rectifiers connected to the power thyratron (on the power supply chassis) cathodes which conduct during a portion of the negative half of the power line cycle because of inductive kickback from the stepping switch coils being driven by the power thyratrons. The time duration of driver thyratron blocking is governed by the RC network between driver thyratron shield grid and ground. Changing the RC network time constant permits decreasing the stepping switch speed to very slow rates, should this ever be desired.

9. AMPLIFIER TEST POINTS: Two test points are provided to permit observation of error amplifier waveform before it reaches the driver thyratrons. They are located alongside V3A and V3B, and are connected directly to the plates of those tubes. To observe the waveform, connect an oscilloscope between either of these points and chassis ground. Waveform observation is useful in troubleshooting, as described in Section 5, Maintenance. Waveform observation also permits gaining greater resolution from the instrument in that one can see how close the instrument is to absolute null. Do not expect a perfectly clean, symmetrical square wave at this point; electrical noise pickup prevents this. The feedback voltage half of the square wave is usually identifiable, since it is generally flatter than the unknown input voltage half. When observing the waveform, beware of a very flat topped pattern as this usually indicates the error amplifier input signals are so large that the error amplifier is saturated. Under such conditions, the waveform will not change in response to small changes in the unknown input voltage.

D. REFERENCE VOLTAGE: The reference voltage is the voltage applied to the input of the stepping switch operated Kelvin-Varley voltage divider. This section will describe each of the various types of reference voltage supplied. Consult Section 1, Specifications, to determine which section below applies to the instrument at hand.

Some general information is presented here before going into the more detailed sections: When measuring absolute voltages, the reference voltage value must be precisely known, or somehow adjusted to the required value. Unsaturated cadmium standard cells provide a stable and precise emf, but the current drawn by the Kelvin-Varley voltage divider cannot be furnished by standard cells without damage to the cells. Therefore, instruments for measuring absolute voltage are provided with an internal electronic reference voltage supply; and the precise emf of unsaturated cadmium standard cells, which are installed in the instrument, is used as a primary reference for maintaining the reference voltage supply output voltage at the proper value. The output voltage of the zener diode type reference voltage supply is manually standardized against the standard cells. The output of the automatically standarized type reference voltage supply is maintained at the proper value by an electronic regulator which compares reference voltage supply output voltage to the standard cells, and makes any necessary corrections to the reference voltage supply output.

In instruments which are designed for voltage ratio measurements, the Kelvin-Varley voltage divider input leads are made accessible externally to permit connection of the external voltage which the instrument is to compare to the unknown input voltage. Ripple and electrical noise from the reference voltage supply, in amounts in excess of the resolution of the instrument, can affect the instrument in the same manner as ripple and noise in the unknown input signal operation. However, ripple and noise in the reference voltage are attenuated by the Kelvin-Varley voltage divider. The amount of attenuation is inversely proportional to divider "position"; that is, attenuation is infinite when the instrument reads all zeros, and zero when the instrument reads all nines. Instruments designed for measuring voltage ratio do not require standardizing.

1. ZENER DIODE REFERENCE VOLTAGE SUPPLY: This section applies only to instruments having a zener diode type reference voltage supply. Comments regarding manual calibration also pertain to some older instruments in which mercury cells supplied the reference voltage.

   The zener diode type reference voltage supply operates as follows: The line voltage is stepped up by the reference supply power transformer; rectified by a full wave semiconductor diode rectifier; filtered; intermediately regulated by a gas reference tube; and

applied, through a series resistor, to the zener diodes which perform the final regulation. The zener diodes act as voltage regulators because, once the zener breakdown voltage is reached, a very constant voltage drop is maintained across them over a wide range of current passed through them. The initial operating current must be the proper value to achieve the full benefit of this effect. Relative freedom from reference voltage drift caused by temperature changes is achieved because matched zener diodes of equal and opposite temperature coefficients are employed. However, drift in reference voltage is natural, especially when the instrument is turned on after being off for a period of time. The reference voltage is returned to its proper value by executing the standardization procedure explained in the next paragraph.

The voltage appearing across the zener diodes is not exactly the value required by the instrument; and it is dropped to its proper value by additional series resistance, part of which is in the adjustable CALIBRATE rheostat described below.

The calibration, or standardization, procedure transfers the accuracy of the standard cells to the reference voltage supply, and is performed as follows: Actuate the CALIBRATE switch on the front panel to connect the standard cell emf into the error amplifier in place of the unknown input. Next, adjust the CALIBRATE control rheostat, which is also accessible from the front panel, until the instrument displays the number which is printed on the decal on the front panel. (Decimal point location is inconsequential since the automatic range unit is ineffectual when the calibrate switch is actuated.) This number is not the value of the standard cell emf; it is higher than the standard cell emf to compensate for the voltage drop in the unknown input voltage caused by the series resistance of the instrument's input filter. The procedure for re-determining this number, if standard cells are replaced, is given in Section 5, Maintenance.

In manually calibrated instruments, the standardization accuracy is increased by performing standardization as close to full scale as is possible. For example, if one standard cell with an emf of 1.0193 volts is used for calibrating a four digit instrument, then an uncertainty of one digit in standardization (because of the instrument's resolution limitations) creates a possible uncertainty of 1/1019, or approximately 0.1%, in standardization. However, if nine standard cells connected in series (emf of approximately 9.1737 volts) are used for standardization, an uncertainty of one digit creates a possible standardization uncertainty of 1/9174, or approximately 0.01%.

2. AUTOMATICALLY STANDARDIZED TYPE: This section applies only to instruments having the automatically standardized type reference voltage, which is supplied by what is called the autocalibrator. See Section 1, Specifications.

   Circuit operating principles are as follows: The output voltage is derived from the cathode circuit of V2B, and is controlled by V2B grid voltage. V2B grid voltage is composed of an approximately correct voltage developed by the gas reference tube, which is mixed with a correction voltage developed in the following manner: A certain fraction of the output voltage is taken off the V2B cathode by a resistive voltage divider, and is fed to one stationary contact of one switch section of a double pole, double throw, electromechanical chopper. The precision emf of an unsaturated cadmium standard cell is fed to the other stationary contact of the same switch section of the chopper. If the attenuated voltage from V2B cathode is not exactly equal to the standard cell voltage, a square wave of voltage is generated by the action of the first set of chopper contacts. This voltage is then amplified by a conventional resistance coupled amplifier, consisting of V1 and the first half of V2. This amplified modulated error signal is demodulated by the second switch section of the chopper, and the DC component forms the correction voltage referred to above. The plate power supplies are conventional. The diode across V2B cathode capacitor protects the capacitor in the event of failure of V2. The cathode capacitor keeps both ends of the output terminal at the same 60 cycle potential, thus making it immaterial which side of the output is grounded. Either side of the output may be grounded, depending on which polarity the associated digital voltmeter displays. Both switch sections of chopper contacts are of the break-before-make type; this prevents discharging the standard cell when the chopper is at rest. The second set of contacts closes about 10^{o} after the first and opens about 10^{o} before, thus avoiding demodulating the transient created when the first set is in motion. A trim pot is provided to permit readjusting the output voltage in the event that the standard cell is replaced by one of slightly different emf.

3. INSTRUMENTS USING EXTERNAL REFERENCE VOLTAGE: See Section 1, Specifications, to determine whether the instrument at hand falls into this category.

   Instruments designed for using external reference voltage supplies are generally employed for measuring the unknown input signal in terms of its ratio to the external reference voltage. Hence, they are often referred to as ratiometers rather than voltmeters. Unlike instruments which measure voltage, ratiometers do not require standardization. The requirements of the external

reference source are as follows:

(a) Its ripple and noise content must not be excessive; see the introductory statements at the beginning of Section 4-2 D.

(b) It must have the proper output voltage. If the reference voltage is too high, readout will be unstable because the two adjacent Kelvin-Varley voltage divider taps nearest the correct value will have, respectively, too high and too low a voltage on them. The error amplifier will issue a "down" pulse in the first case and an "up" pulse in the latter, not finding a tap which will satisfy the system. The instrument will generally operate satisfactorily over its entire range with a reference voltage 20% higher than nominal, and it may operate over many sections of its range with a reference voltage 50% higher than nominal. The instrument's dead-spot, or resolution, or sensitivity, is directly proportional to reference voltage amplitude, and will be halved if the reference voltage is halved, etc. Readjusting the error amplifier gain control to achieve a higher or lower amplifier gain will, within the latitude of gain control, permit proper instrument operation with lower and higher reference voltages, respectively.

(c) It must be connected to the proper terminals on the instrument.

Refer also to Section III, Operating Instructions, for specific connection information.

4. STANDARD CELL CHARACTERISTICS: The unsaturated cadmium standard cell provides an emf of sufficient accuracy for digital voltmeter use; has a relatively small temperature coefficient; and can be inverted. The unsaturated cadmium standard cells used in Non-Linear Systems Digital Voltmeters supply an emf which is constant within ±0.01% from 4° C to 40° C, and which may increase by an additional 0.015% between 50° C and 60° C. The cells used by Non-Linear Systems are virtually free of hysteresis for periods as long as five years.

With standard cells, the following precautions should be observed:

(a) Avoid drawing current from the standard cells. One hundred microamps may be drawn for several minutes without permanently affecting the emf. Current drains should be as low as possible and for only short periods of time. The emf of short circuited cells should be accurately measured and observed before re-use. As long as a month may be required

for a cell, which has been short circuited for a 1/2 hour, to recover to within 0.01% of its original value, if it does so at all. It is best to replace any cells which have been short circuited. Approximately 0.01 microamp is drawn while depressing the CALIBRATE control on digital voltmeters with manual calibration and nine internal standard cells, and approximately 0.001 microamps drawn when using one internal standard cell. A 100 K protective resistor, in series with the standard cells, furnishes protection in the event of vacuum tube structural failure, etc.

(b) Store the cells vertically; inverted storage, for protracted periods, can result in emf changes.

(c) Store the cells at normal room temperature, or slightly below. Storage at 80° F can cause an 0.01% decrease in emf after a year.

(d) Avoid subjecting the cells to temperatures greater than 130°F or less than 39° F.

(e) Tests show that cells will stay within ±0.01% of their room temperature emf when soaked at -16° C (3.2° F). emf may drop to less than one volt at -30° C (-22° F). When again exposed to room temperature, the emf normally recovers to within 0.1% of original room temperature emf in six to twelve minutes.

(f) Where continued high accuracy must be assured, check the standard cell emf at least once every 6 months.

(g) Remember, standard cells, like any other source of electrical energy, have an internal resistance; and this resistance causes the terminal voltage to drop when an electrical load is applied. Generally, standard cell internal resistance is between 500 and 1500 ohms.

E. POWER SUPPLY ASSEMBLY: Most models derive B^+ or B- voltage from conventional semiconductor rectifiers energized by a winding on the power transformer; but in some models a semiconductor voltage doubler circuit, also energized by a winding on the power transformer, is utilized. Supply filtering is generally performed right at the amplifier chassis where the filters also act to decouple the stages of amplification from one another. Additional separate windings on the power transformer furnish general filament voltage, separate filament supplies for each power thyratron, and excitation voltage for the digital readout lamps. Other major components, also mounted on the power supply chassis, are: 1) the hum control (moved to lower rear

section of error amplifier in some instruments); 2) power thyratrons which act as final power amplifiers and drive the stepping switches in response to error amplifier commands; 3) time delay relay to keep power thyratron plate power off until sufficient time has elapsed for the filament to become heated; 4) speed control circuit diodes; 5) automatic print control components (see section on data recording accessories, which is included only when an instrument is provided with such features).

F. AC TO DC CONVERTER - Not applicable to schematics dated prior to 1/9/58: The AC to DC converter, present in AC-DC digital voltmeters (see section 1, Specifications), accurately converts unknown AC voltages into DC voltages which are then measured by the DC digital voltmeter section of the instrument. The unknown AC input voltage is attenuated, in precise increments, by an input attenuator to permit covering a wide input voltage range. The attenuator is frequency compensated. The attenuator output is fed into a high input impedance isolation amplifier, V1 and V2. The isolation amplifier output is then fed into a frequency compensating summing network. Here it is summed with a 180° out of phase feedback voltage derived from the converter output stage. This summed signal's amplitude and phase (0° or 180° with respect to the unknown AC input signal) are a measure of error and direction of error, respectively, in the rectification system in the converter output stage. This summed signal is amplified by a high gain AC amplifier and rectified by semiconductor diodes. The half wave output of one diode is filtered, and forms the DC output of the AC to DC converter. The feedback signal is obtained by mixing together the half-wave outputs of both semiconductor diodes. This high gain feedback system linearizes and stabilizes the rectification characteristic of the diodes.

When the AC to DC converter output exceeds full scale, a circuit associated with the DC digital voltmeter automatic range changing circuit causes the word "OVERLOAD" to appear in the digital readout; thereby, warning that the operator should move the AC range switch to select a higher voltage range.

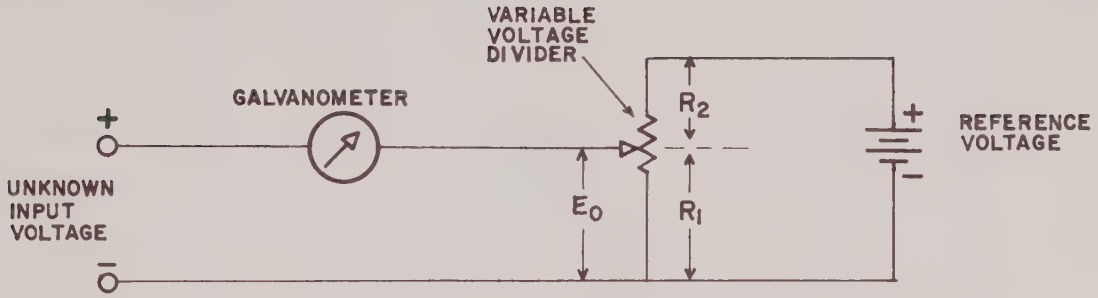


FIGURE 4-1. BASIC POTENTIOMETER CIRCUIT

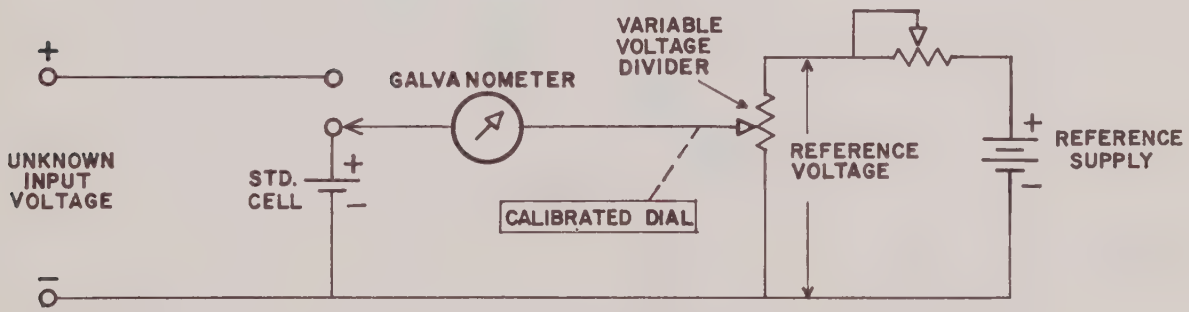


FIGURE 4-2. POTENTIOMETER WITH CALIBRATION RHEOSTAT.

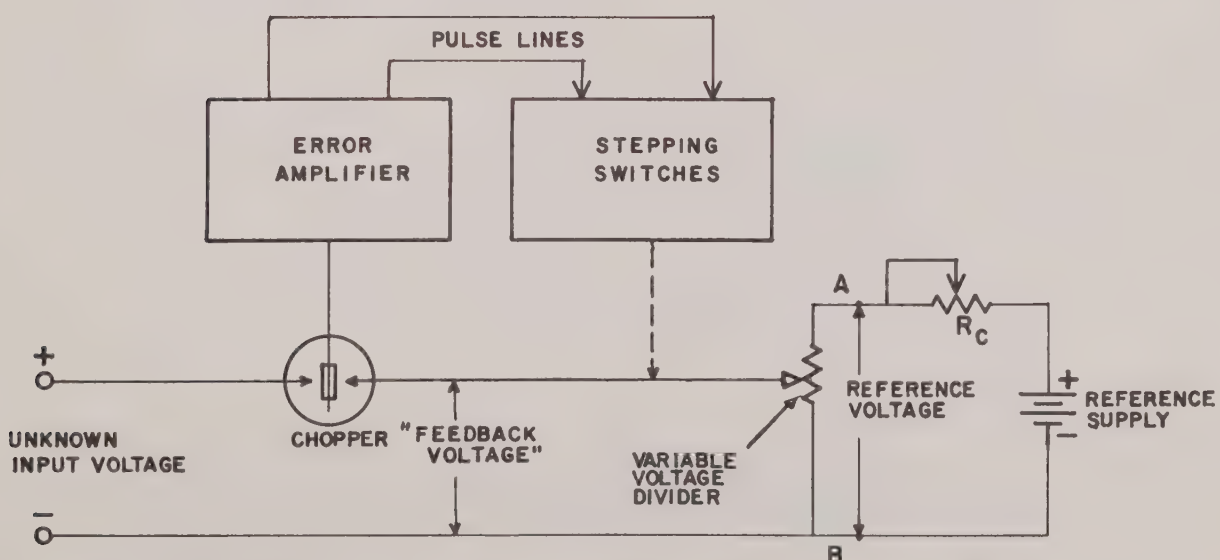


FIGURE 4-3 SIMPLIFIED SCHEMATIC, SINGLE RANGE DIGITAL VOLTMETER FOR MEASURING ABSOLUTE DC VOLTAGES

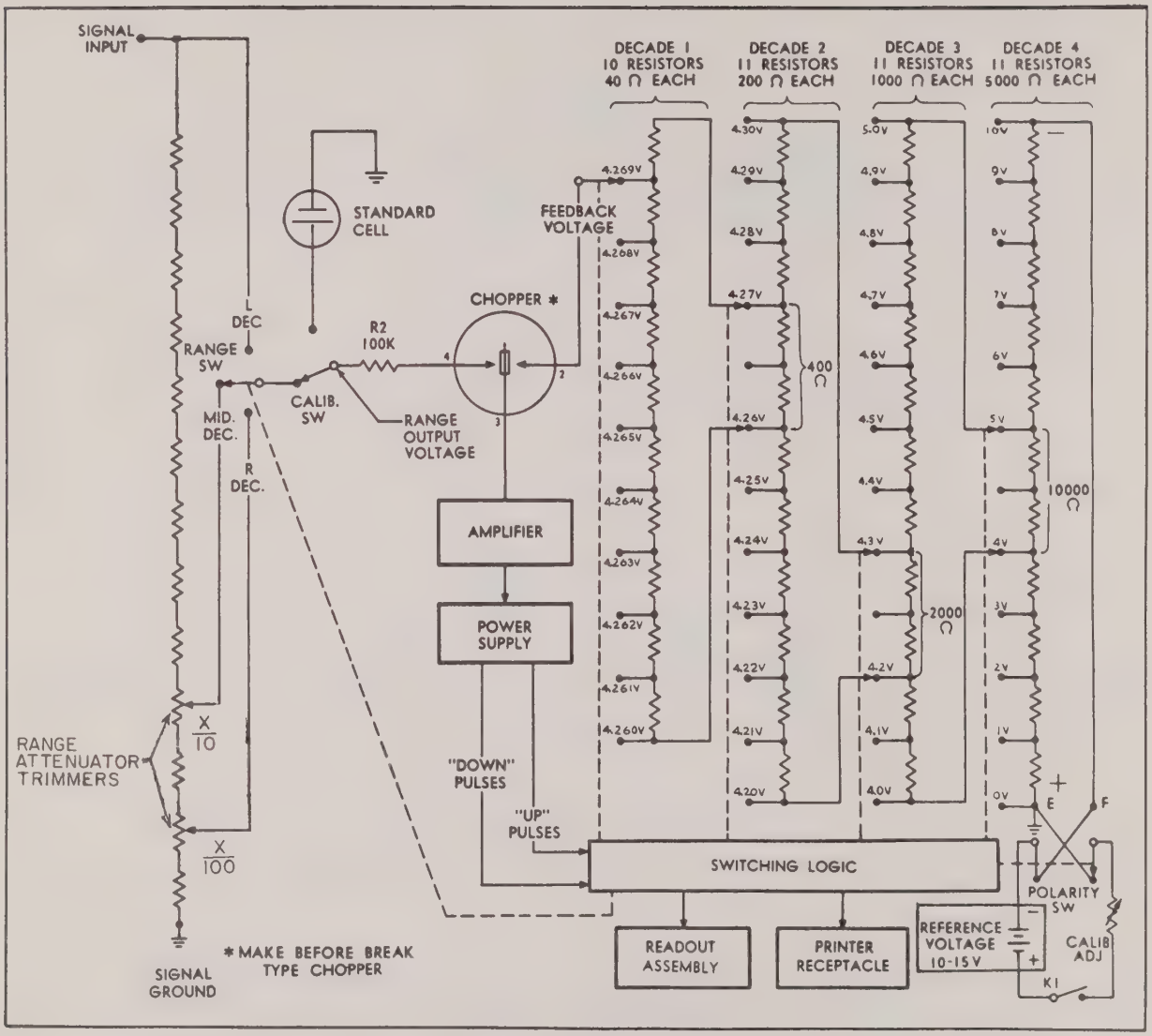


FIGURE 4-4. SIMPLIFIED CIRCUIT DIAGRAM: 4-DIGIT, MULTIRANGE, MANUALLY STANDARDIZED DIGITAL VOLTMETER FOR MEASURING ABSOLUTE DC VOLTAGES.

NOTES: 1. In multirange, three digit instruments, the range attenuator also has an $\frac{X}{1000}$ tap, while five digit instruments have only an $\frac{X}{10}$ tap.

2. In instruments with automatic standardization, the calibrate switch, standard cell, and calibrate adjust rheostat are eliminated from this circuit, and are effectively in the autocalibrator.

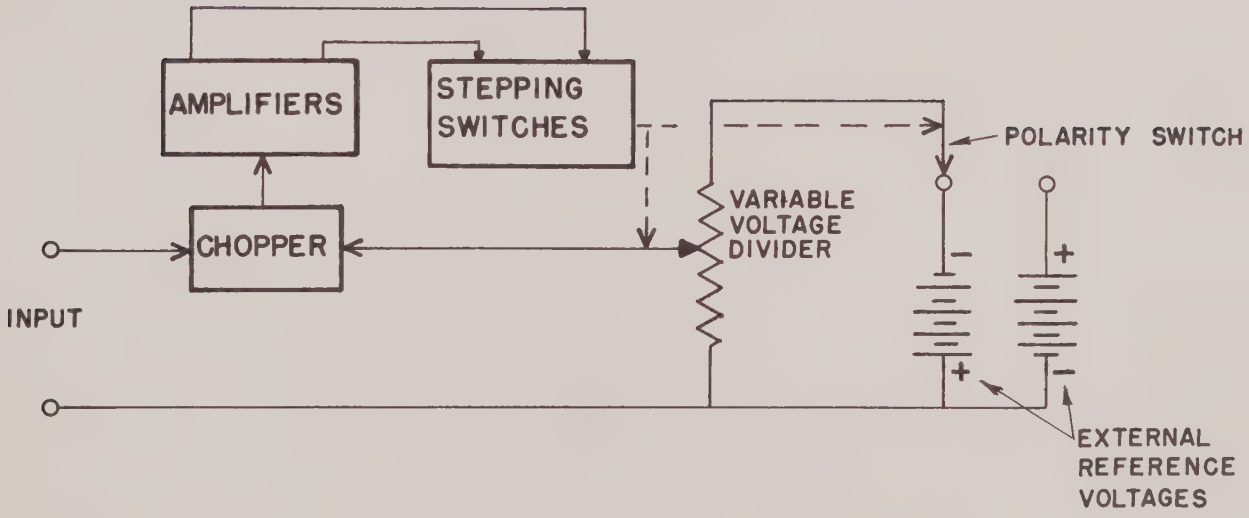
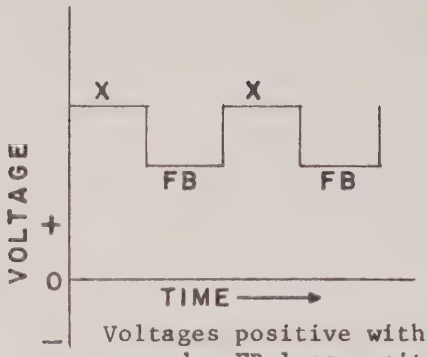
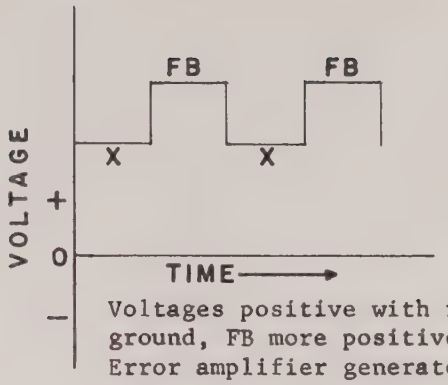


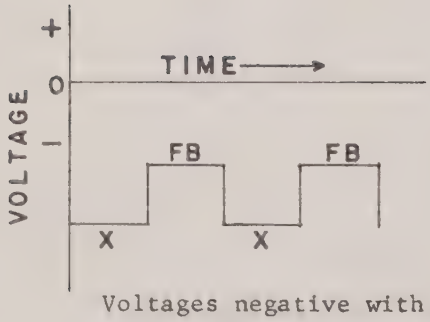
FIGURE 4-5. SIMPLIFIED SCHEMATIC, DIGITAL VOLTMETER FOR MEASURING DC VOLTAGE RATIOS.



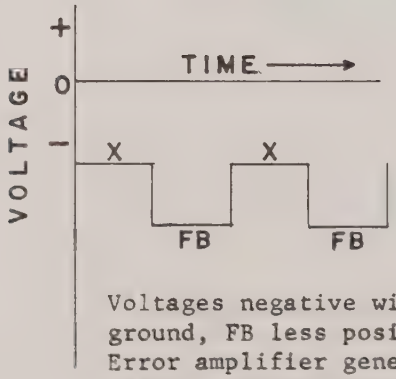
Voltages positive with respect to ground. FB less positive than X. Error amplifier generates "up" pulses, decade switches get "up" pulses.



Voltages positive with respect to ground, FB more positive than X. Error amplifier generates "down" pulses, decade switches get "down" pulses.



Voltages negative with respect to ground, FB more positive than X. Error amplifier generates "down" pulses, decade switches get "up" pulses because polarity switch reverses pulse lines.



Voltages negative with respect to ground, FB less positive than X. Error amplifier generates "up" pulses, decade switches get "down" pulses because polarity switch reverses pulse lines.

X = Unknown input voltage
FB = Feedback voltage

FIGURE 4-6. CHOPPER OUTPUT WAVEFORM AND RESULTING PULSES AT ERROR AMPLIFIER OUTPUT AND TO DECADE SWITCHES FOR VARIOUS RELATIONS BETWEEN UNKNOWN INPUT AND FEEDBACK VOLTAGE.

SECTION V

MAINTENANCE

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SECTION V

MAINTENANCE

5-1. ACCESS TO AND REMOVAL OF SUBASSEMBLIES: Figure 5-1 shows the location of the main assemblies in rack mounted and bench type instruments as viewed from the front. In order to gain access to the components on the sub-assemblies shown in Figure 5-1, it is necessary only to remove the hood on the rack mounted instruments. On bench types, the front and rear panels, as well as the hood, must be removed. In both cases, this is accomplished by removing the Phillips-head screws. The individual components on the power supply, amplifier, automatic calibrator, or AC-DC converter are exposed by removing the retaining screws and withdrawing these assemblies from their aluminum mounting structure channels. Parts inside the stepping switch assembly tank can be exposed by removing the screws around the periphery of the stepping switch assembly etched circuit board and lifting the entire stepping switch assembly from the tank. Caution should be exercised to prevent damage to this assembly, particularly to the stepping switch wipers. If the various assemblies are removed from their normal locations in the chassis, placed on a bench, and reconnected with the supplied interconnecting cables, the digital voltmeter can be operated. This feature facilitates checking voltages and waveforms when trouble shooting. Remember, however, operating the instrument without its hood increases electrical noise pickup.

5-2. DC INSTRUMENT ADJUSTMENT, CALIBRATION, AND TEST.

A. GAIN SETTING.

1. GENERAL: For best results, the digital voltmeter should be operated with the amplifier gain set at one digit. It is important to remember, that instruments having automatic gain control (consult error amplifier schematic and refer to Section 4-2(c) maintain one digit resolution only below 10% of full scale on each range. Therefore, error amplifier gain in these instruments should be adjusted to be one digit below only 10% of full scale on the low range, where the automatic gain control is ineffectual. Consult Section 1, Specifications, to determine how much resolution to expect. If the amplifier gain is not set high enough, the resolution of the digital instrument will be too low. On the other hand, excessively high amplifier gain settings may cause instability of the readout display.

   One of the following procedures should be used when adjusting amplifier gain, depending upon the type of digital instrument at hand:

2. GAIN SETTING, MANUALLY CALIBRATED INSTRUMENTS: These instruments have a "CALIBRATE" button on the front panel. Depress this button. After the visual readout has come to a balance, slowly turn the slotted calibration rheostat shaft in a counter-clockwise direction.

This shaft is accessible through a hole in the front panel near the "CALIBRATE" button. Observe the magnitude of the decrease in readout display. If the readout display decreases in steps of one digit and does not become unstable, no adjustment of amplifier gain is necessary. If slowly rotating the calibration rheostat in a counter-clockwise direction results in a decrease of two or more digits in the rightmost window, the amplifier gain should be increased by slightly turning the slotted gain control potentiometer on the amplifier in a clockwise direction. Again, observe the number of digits by which the readout display decreases when the calibrate rheostat shaft is slowly turned counter-clockwise. Repeat the amplifier gain adjustment, if necessary, to obtain a readout display decrease of one digit in the rightmost window. If instability develops in the readout display, turn the amplifier gain control counter-clockwise until the instability just disappears and the readout display decreases in steps of one digit in the rightmost window as the calibration rheostat shaft is slowly turned counter-clockwise.

3. GAIN SETTING, AUTOMATICALLY CALIBRATED INSTRUMENTS: Digital instruments which derive their working reference voltage from an internal automatic calibrator unit are not supplied with a "CALIBRATE" button and a calibrate rheostat control shaft on the front panel. Thus, an outside source of finely adjustable voltage, in a range from 0-10 volts, must be applied to the input terminals of the instrument when making an amplifier gain adjustment. The amplifier gain adjustment is made for automatically calibrated instruments in the same way as for mercury battery or zener diode reference supply instruments, except that the external unknown input voltage is manipulated, rather than the calibrate rheostat, in order to obtain a controlled decrease in readout display.

4. GAIN SETTING, EXTERNAL REFERENCE TYPE INSTRUMENTS: To adjust the amplifier gain setting on a digital ratiometer, the following procedure should be used:

   Ascertain that the external reference voltage is set for the proper value, (See Section 1, Specifications). Apply a signal to the input terminals of the ratiometer; this signal may be derived from a separate DC power supply, or may be the output of a potentiometer which is connected to the ratiometer external reference supply. Control the applied signal and adjust the amplifier gain control for a one digit decrease of the visual readout display, without instability, as previously described.

B. HUM CONTROL ADJUSTMENT: To adjust the hum control, which is located on the error amplifier or power supply chassis (consult schematics) proceed as follows:

Turn on the digital voltmeter. Depending upon the number of digits available in the readout, apply the voltage shown in Table 5-1 to the input terminals.

Table 5-1

No of digits In Readout	Input Voltage
3	1.00 to 99.9
4	10.00 to 99.99
5	above 100.00

Connect an oscilloscope between ground and either of the two test points on the error amplifier assembly. You should see a square wave. For a clearer view, it may be desireable to increase its amplitude by slightly adjusting either the unknown input voltage, or, in manually calibrated instruments, the calibrate rheostat shaft. However, if the square wave amplitude is increased too much, the visual readout display will change; this should be avoided. Adjust the hum control in either direction for optimum squareness of the oscilloscope picture.

Early NLS digital instruments were supplied with a non-polarized input plug on the AC power input cord; and in some locations it was found necessary to reverse the power plug position in the receptacle to reduce the hum.

C. STANDARDIZATION AND AUTOCALIBRATOR ADJUSTMENTS: As indicated in Section 4, absolute voltages cannot be accurately measured by potentiometric instruments such as digital voltmeters, unless they are first standardized against a suitable voltage standard such as an unsaturated cadmium standard cell. NLS digital voltmeters have one or more such standard cells installed to relate the measurements made by the digital voltmeter to the absolute volt.

CAUTION: All standard cells have an internal resistance which causes a voltage drop internal to the standard cell whenever current is drawn from it. Do not expect the terminal voltage of a standard cell under load to be equal to the tagged or open circuit voltage of the cell. If a battery of nine standard cells in series is connected to the input terminals of a digital voltmeter having a ten megohm input impedance, the digital voltmeter will display a measured voltage that may be as much as ten digits lower than the sum of the voltage recorded on each standard cell tag.

NOTE: There is an emf value, accurate to 0.1%, permanently printed on each standard cell. All cells, however, are measured to an accuracy of ±0.01%, and this measured value is used in calculating the correct readout display when standardizing the digital voltmeter. If you are in doubt as to the emf of a standard cell, contact NLS and give the standard cell serial number and the digital voltmeter serial and model number.

1. MANUALLY STANDARDIZED INSTRUMENTS: To standardize instruments having the manual standardization feature (See Section 1, Specifications), proceed as instructed in Section 3, Operating Instructions.

2. STANDARDIZING THE AUTOMATIC CALIBRATOR: In instruments where the working reference voltage is obtained from an electronic automatic calibrator built into the instrument, no provision has been made for standardization by controls immediately accessible from the front panel. Autocalibrator output is 1.0 volts in three digit, 10 volts in four digit, and 100 volts in five digit instruments. Some early model three digit instruments used a 10 volt auto-calibrator.

   The output voltage of an automatic calibrator is standardized to the correct value at the factory. If the standard cell built into the calibrator is replaced with a new cell whose emf is not equal to that of the original cell, the calibrator must be readjusted. For this reason, a slotted shaft standardizing adjustment is readily accessible when the cover plate is removed from the front panel. Adjust the automatic calibrator as follows

   (a) Turn on the digital voltmeter. Allow 15 minutes for warm-up.

   (b) Connect a known voltage to the input terminals of the digital voltmeter. For best accuracy, the chosen value of this voltage should be between 90% and 99% of full scale on any range of three and four digit instruments, and between 10% and 99% of full scale on any range in five digit instruments.

   (c) Adjust the calibrate rheostat on the front panel of the calibrator chassis until the digital voltmeter display is equal to the known voltage connected to the input terminals of the digital voltmeter.

   NOTE: A convenient source of known voltage, to connect to the digital voltmeter in step (b) above, is a bank of nine standard cells in series. If the digital voltmeter has an input impedance of 1000 megohms on the 0 to 10 volt scale, insignificant error will result from this load on the standard cells. If, however, the digital voltmeter has a lower (10 to 11 megohm) input impedance, the range unit should be temporarily disconnected during the calibration standardizing procedure, in order to eliminate standard cell loading errors. If it is inconvenient to disconnect the range unit, a correction must be made for the effect of the internal resistance of the standard cells, the voltage division performed by the digital voltmeter input filter choke resistance, and

overall resistance of the range unit (See Figure 5-3).

In the event that the only standard cell available is the one in the calibrator, standardization adjustment should be made to obtain a readout display of 1019 when the positive input terminal of the digital voltmeter is connected to pin 1 of the chopper in the autocalibrator. CAUTION: DO NOT SHORT CIRCUIT THE STANDARD CELL DURING THIS OPERATION. It must be pointed out that standardization by means of the standard cell in the automatic calibrator is not a check on the accuracy of the standard cell voltage; an independent standard cell is necessary to accomplish this. Furthermore, the low voltage of one standard cell (which is little more than one volt, and only 10% of full scale in three and four digit instruments) imposes serious limitations on accuracy of this adjustment. This is because a standardization adjustment error of one digit at 10% of full scale can result in an error of ten digits at full scale.

D. FEEDBACK VOLTAGE LINEARITY TEST: One of several factors which may affect the accuracy of measurements made with digital voltmeters is the linearity characteristic of the Kelvin-Varley voltage divider. The digital Kelvin-Varley circuit develops a known feedback voltage, within the digital voltmeter, to which the unknown input voltage is compared during measurement. Many methods for testing the linearity of the digital Kelvin-Varley voltage divider exist, but the method described below has been found most satisfactory. It is assumed that error amplifier gain is properly adjusted before the test is started.

Only one piece of precision test equipment is required, a variable voltage divider with an accuracy five to ten times better than that of the digital instrument under test, and with an input resistance of 100,000 ohms (this high to prevent excessive current drain from the reference supply). Connect the digital instrument as shown in Figure 5-7A if it is a digital ratiometer, and as shown in Figure 5-7B, if it is an absolute voltage measuring digital voltmeter. Observe the shielding and grounding rules given in Section 3, Operating Instructions. Adjust the standard divider to a reading of 00000; the visual readout should display to be zero in each window. Adjust the standard voltage divider to read 99990 (00000 and 99999 for 5 digit instruments, and 00000 and 99900 for 3 digit instruments); the visual readout display should be nine in each window. These two readout displays must be obtained for the indicated standard divider settings. If the instrument displays digits other than those indicated above for these two end points, an improper circuit condition exists and must be located and corrected before proceding with the test. Now set the standard

divider for various readings such as, for a 4-digit instrument, .89990, .7990, .69990, ----.08990, .07990, ----.00890, .00790, ----.00080, .00070, ----etc. The digital instrument visual readout display should be equal to the standard divider settings, or be within the linearity tolerance given in Section 1, Specifications.

It is often very convenient to use an adapter plug to facilitate connection of the standard voltage divider to the digital voltmeter and the internal source of working reference voltage. Figure 5-7B shows the wiring of such an adapter. The readout display should correspond with the two end point settings (00000 and 99990) of the standard voltage divider. If they agree, proceed with the rest of the test as described above for other settings of the standard voltage divider.

CAUTION: Do not use the adapter wiring shown in Figure 5-7B unless this circuitry is compatible with the wiring of the digital instrument to be tested. CONSULT CIRCUIT DIAGRAMS FURNISHED WITH THE INSTRUMENT TO BE TESTED.

One very desireable feature of the ratiometer method of testing voltage divider linearity is that reasonably large (20%) deviations in reference voltage from the nominal value of reference voltage have no significant effect upon test accuracy. This is true because the same voltage is furnished to the input of the internal voltage divider as well as the input of the external standard voltage divider. Thus, for equal settings of the two voltage dividers, the output voltages are equal if the input voltages are equal.

As an alternative method: The digital voltmeter linearity can be tested by connecting a stable and finely adjustable DC voltage source to its input terminals, monitoring this input voltage with a precise laboratory type potentiometer, varying the input voltage, and observing whether the digital voltmeter readings are proportional to the precision potentiometer readings within the accuracy limitations of both measuring devices. The advantage of this method is that all connections to the digital voltmeter are external when using this method. The disadvantage is that uncompensated drifts of the digital voltmeter or precision potentiometer reference voltages during the test will give a false indication that the digital voltmeter linearity is not within tolerance.

E. RANGE UNIT ADJUSTMENT: The range unit will require scale factor readjustment only if the range unit resistors change their ohmic value, or if the electrical loading of the unit output taps changes. The adjustment method described below requires several accurate voltage dividers and a stable DC source. This method permits accurate range unit scale factor adjustment regardless of any inaccuracies present in the digital Kelvin-Varley voltage divider. This is because, in the prescribed method, the Kelvin-Varley divider is always brought back to the same position (same numerical display on digital voltmeter, ignoring decimal point location) when the correspondence of scale factors on each range is checked. As in any other test, proper shielding and grounding techniques must be followed to prevent electrical noise pick up from interferring with the instrument's stability and resolution. Also, in checking each range, best accuracy is achieved when the test voltage used is as close to full scale for that range as is practicable. The precision voltage divider used is the range unit adjustment procedure must be compensated for the electrical loading effect of the digital voltmeter. The precision voltage divider accuracy should be five to ten times better than the accuracy to which the range unit is to be adjusted.

The range trim potentiometers referred to below are located at the top rear of the stepping switch assembly. This slotted shaft adjustment is accessible without removing the stepping switch assembly from the stepping switch tank. In earlier NLS instruments, the range trim potentiometers are located inside the stepping switch tank, and it is necessary to remove the stepping switch assembly from the tank to gain access to them.

ADJUSTING THE 10 VOLT RANGE SCALE FACTOR

This adjustment is present only in multi-range instruments having, among any other ranges, a lowest full scale range of one volt and a ten volt range (e.g. Model 351).

1. Connect the terminals of a 10 to 1 precision voltage divider to a stable DC source of approximately 9.5 to 9.9 volts.

2. Connect the input terminals of the digital voltmeter under test to the input of the voltage divider; observe the readout display and the waveform at the error amplifier test points.

3. Connect the input terminals of the digital voltmeter to the output terminals of the voltage divider; observe the readout display and error amplifier waveform.

4. The 10 volt range is properly adjusted when the readout display in step 3 is exactly equal to one-tenth of the readout display observed in step 2 (for example: 9.65 in step 2 with .965 in step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in step 2. If this correspondence is not present, adjust the 10 volt range trim potentiometer.

ADJUSTING THE 100 VOLT RANGE SCALE FACTOR

This adjustment is present only in multi-range instruments having, among other ranges, full scale ranges of 10 volts and 100 volts (e.g. Models 351 and 451).

For instrument whose lowest range is 10 volts full scale (e.g. Model 451) proceed as follows:

1. Connect the input terminals of a 10 to 1 precision voltage divider to a stable source of voltage, in the neighborhood of 95 to 99 volts.

2. Connect the input terminals of the digital voltmeter under test to the input of the voltage divider; observe the readout display and waveform at the error amplifier test points.

3. Connect the input terminals of the digital voltmeter to the output terminals of the voltage divider; observe the readout display and error amplifier waveform.

4. The 100 volt range is properly adjusted when the readout display in step 3 is exactly equal to one-tenth of the readout display observed in step 2 (for example: 95.93 in step 2, compared to 9.593 in step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in step 2. If this correspondence is not present, adjust the 100 volt range trim potentiometer.

For instruments whose lowest range is one volt (e.g. Model 351), proceed as above; except use a 100 to 1, rather than a 10 to 1, voltage divider, and adjust the 100 volt range trimmer for a readout display in step 3 to be one-hundredth of that observed in step 2 (e.g., 95.9 in step 2 compared to .959 in step 3).

ADJUSTING THE 1000 VOLT RANGE SCALE FACTOR

1. Connect the input terminals of a 100 to 1 voltage divider to a stable source of DC voltage as close to 999 volts as is practicable. (Lower voltages, certainly no less than 200 volts, can be used, but accuracy will not be as good as when higher voltages are used).

2. Connect the input terminals of the digital voltmeter under test to the input terminals of the voltage divider; observe the readout display and waveform at the error amplifier test points.

3. Connect the input terminals of the digital voltmeter to the output terminals of the 100 to 1 voltage divider; observe the readout display and error amplifier waveform.

4. The 1000 volt range is properly adjusted when the readout display in step 3 is exactly one-hundredth of the readout display observed in step 2 (for example: 982.3 in step 2, compared with 9.823 in step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in step 2. If this correspondence is not present, adjust the 1000 volt range trim potentiometer.

5-3. AC TO DC CONVERTER ADJUSTMENTS: This section describes the procedure for readjusting the scale factor and frequency response of the wide frequency range AC to DC converter (those used in instruments with a "W" suffix, e.g., 3511W, 3512W, 4511W, 4512W, 5512W, etc.). The same procedure is followed for narrow frequency band or single frequency AC to DC converters (those used in "N" suffix instruments, e.g., 3512N, 4511N, etc.), except there is no requirement for changing the AC input frequency when the "N" models are calibrated. In the procedure which follows, it is assumed that the DC output of the AC to DC converter is being measured by a DC digital voltmeter. If this is not the case, then a DC potentiometer of adequate accuracy and high input impedance must be employed. The AC to DC converter normally operates into a ten megohm load; and, since the converter's output impedance is very high, load resistance must be considered if the converter's output is not connected to an NLS DC digital voltmeter.

First, observe the following precautions:

1. The calibration signal source must be stable.

2. The calibration signal source waveform must be sinusoidal with low harmonic distortion, or inaccuracies, caused by harmonic distortion, will be introduced. Remember, the AC to DC converter is designed for measuring sinusoidal voltages; detects the average value of the input waveform; and is calibrated at the factory to indicate the RMS value of a pure sine wave. If the signal waveform is not a pure sinusoid, do not expect the AC to DC converter to agree with an AC instrument which detects the waveform RMS value (thermal converters, dynamometric type voltmeters, torque-type converters; etc.) Typical deviations to be expected are:

SECOND HARMONIC

% Harmonic	Maximum Error Expected
10%	0.5%
20%	2%
50%	12%

THIRD HARMONIC

10%	4.5%
20%	8%
50%	22%

3. Before calibrating the AC to DC converter, calibrate the DC voltage measuring section of the digital voltmeter using the procedure given in this handbook.

4. Use shielded leads and a good ground, to prevent noise pick-up problems; and use a common ground point, to avoid circulating current problems.

5. One input terminal of the AC to DC converter is connected to the chassis. Avoid burning out the ground wiring by improper connection of the AC input signal voltage, which can easily occur if it is not isolated from the AC power line.

6. Do not expect the digital voltmeter reading to change in steps of one digit in the rightmost window over its entire range; because the automatic gain control circuit is connected into the DC digital voltmeter error amplifier, when the instrument is switched to AC voltage ranges (See Theory of Operation, Section 4).

7. For the best results, permit the AC to DC converter to warm up for at least one hour, and preferably 2 1/2 hours, before testing or readjusting its accuracy.

8. When using AC voltage dividers, remember, they must be frequency compensated; and, at high frequencies, the loading caused by test wiring capacitances and AC to DC converter input capacitance (See Section 1, Specifications) can cause appreciable loading. For this reason, test leads should be as short as possible.

Two methods of calibrating the AC to DC converter are given here; selection of method depends on the test equipment available.

CALIBRATION METHOD #1 (Not applicable to schematics dated prior to 1/9/58): If stable, sinusoidal, accurately known AC sources, whose nominal values are approximately 9.500, 95.00, and 950.0 volts RMS, are available, use the following procedure for calibration:

1. ADJUSTING THE 10 VOLT RANGE:

   (a) Connect 9.500 volts RMS at some frequency between 80 to 200 cps to the AC to DC converter input, with the converter on its 10 volt range. Adjust R21 until the digital voltmeter reading agrees with the known value of the nominal 9.500 volt input.

   (b) Change the frequency of the nominal 9.500 volt RMS input to 10,000 cps (+0%, -10%). Adjust C15 until the digital voltmeter reading agrees with the known value of the nominal 9.500 volt input. If C15 does not have sufficient range of adjustment to accomplish this, then C16 requires readjustment. To accomplish this, proceed as follows. With an input voltage of approximately 9.5 volts RMS at 10,000 cps (+0%, -10%) connected to the AC to DC converter:

      (1) Adjust C15 for a minimum reading on the digital voltmeter.

      (2) Adjust C16 to further minimize the digital voltmeter reading.

      (3) Adjust C15 until the digital voltmeter reading agrees with the known value of the nominal 9.500 volt, 10,000 cps input.

   (c) Repeat step 1(a). Slight readjustment of R21 is normally required if, before C15 was adjusted, the calibration was high or low by more than 1% of the reading. If R21 is readjusted, repeat steps 1(b) and 1(c).

      NOTE: Adequate correction should be obtainable with C15 alone. Should C15 and C16 both require adjustment in step 1(b), malfunction or deterioration of one or more components is to be suspected. For further details, see Section 5-4, Troubleshooting.

2. ADJUSTING THE 100 VOLT RANGE:

   (a) Switch the AC to DC converter to its 100 volt range. Connect the nominal, but accurately known, 95.00 volt RMS source, of the frequency selected in 1(a) above, to the

converter. Adjust R3 until the digital voltmeter reading agrees with the known value of the nominal 95.00 volt RMS source.

(b) Change the source frequency to 10,000 cps (+ 0%, - 10%). Adjust C6 until the digital voltmeter reading agrees with the known value of the nominal 95.00 volt source.

(c) Repeat step 2(a). If R3 is readjusted, repeat steps 2(b) and 2(c).

3. ADJUSTING THE 1000 VOLT RANGE:

(a) Switch the converter to its 1000 volt range. Connect the nominal, but accurately known, 950.0 volt RMS source, of the frequency selected in step 1(a) above, to the converter. Adjust R5 until the digital voltmeter reading agrees with the known value of the nominal 950.0 volt RMS source.

(b) Connect a nominal 95.00 volt RMS, 10,000 cps (+ 0%, - 10%), source to the converter. Adjust C5 until the digital voltmeter reading agrees with the known value of the input voltage.

(c) Repeat step 3(a). If R5 is readjusted, repeat steps 3(b) and 3(c).

CALIBRATION METHOD #2 (Not applicable to schematics dated prior to 1/9/58): Where accurate, stable sources of 9.5, 95, and 950 volts are not available (as needed for Calibration Method #1), the following procedure, which requires stable sources but only an accurate 9.5 volt source, should be used:

1. TO ADJUST THE SCALE FACTOR AND FREQUENCY RESPONSE OF THE CONVERTER 10 VOLT RANGE:

   (a) Apply a stable and accurately known sinusoidal voltage of 9.550 volts RMS at a frequency of 200 cps ±10% to the converter input terminals.

   (b) Switch the converter's AC voltage range selector switch to the 10 volt range and adjust R21 (front panel 10 volt calibration adjustment) until the digital voltmeter reading agrees with the known value of the AC input voltage.

   (c) Change the input voltage frequency to 10,000 cps (+0%, -10%). The digital voltmeter reading should agree with the known value of the AC input voltage, which should be approximately 9.550 volts and accurately known. If the digital voltmeter reading is either high or low by more than 0.1% of the reading, adjust C15. If C15 does not have sufficient range of adjustment to accomplish this, then C16 requires readjustment. To accomplish this, proceed as follows: With an input voltage of approximately 9.5 volts RMS at 10,000 cps (+0%, -10%) connected to the AC to DC converter:

      (1) Adjust C15 for a minimum reading on the digital voltmeter.

      (2) Adjust C16 to further minimize the digital voltmeter reading.

      (3) Adjust C15 until the digital voltmeter reading agrees with the known value of the nominal 9.500 volt, 10,000 cps input.

   (d) Repeat step 1(a). Slight readjustment of R21 is normally required if, before C15 was adjusted, the calibration was high or low by more than 1% of the reading. If R21 is readjusted, repeat steps 1(b) and 1(c).

   NOTE: Adequate correction should be obtainable with C15 alone. Should C15 and C16 both require adjustment in step 1(b), malfunction or deterioriation of one or more components is to be suspected. See Section 5-4, Troubleshooting, for further details.

(e) The 10 volt range is now adjusted properly. Do not readjust R21, C15, or C16 during subsequent steps.

2. THIS STEP MEASURES THE AC TO DC CONVERTER AMPLITUDE LINEARITY AT HIGH AND LOW FREQUENCIES. THE DATA FROM THIS STEP IS REQUIRED IN PERFORMING THE REMAINING ADJUSTMENTS.

(a) Low Frequency Linearity Test

(1) Apply a stable, sinusoidal, voltage, whose amplitude is approximately 9.550 volts RMS, and whose frequency is 200 cps $\pm$ 10%, to the input of an AC voltage divider. The voltage divider output voltage should be one-tenth of the input voltage at the frequency selected and with the load of the AC to DC converter connected to the voltage divider output. Voltage divider accuracy should be, at worst, $\pm$ 0.02%. (Precision tapped transformers, such as the Gertsch Variable Turns Ratio Transformer, are excellent voltage dividers for this purpose).

(2) Connect the AC to DC converter to the voltage source of step 2(a)(1) with the voltage divider of step 2(a)(1) connected. Starting with the voltage source adjusted for less than 9.550 volts, slowly increase the voltage until the digital voltmeter reading just changes to 9.550 volts.

(3) Connect the AC to DC converter to the output of the voltage divider of step 2(a)(1) and record the resultant reading.

(b) High Frequency Linearity Test

(1) Apply a stable, sinusoidal voltage, whose amplitude is approximately 9.550 volts RMS, and whose frequency is 10,000 cps $\pm$ 10%, to the input of an AC voltage divider. The voltage divider output voltage should be one-tenth of the input voltage at the frequency selected and with the load of the AC to DC converter connected to the voltage divider output. Voltage divider accuracy should be, at worst, $\pm$0.02%. (Here again, the Gertsch Transformer is excellent).

(2) Connect the AC to DC converter to the voltage source of 2(b)(1) with the voltage divider of 2(b)(1) connected. Starting with the voltage source adjusted for less than 9.550 volts, slowly increase the voltage until the digital voltmeter reading just changes to 9.550 volts.

(3) Connect the AC to DC converter to the output of the voltage divider of step 2(b)(1) and record the resultant reading.

3. TO ADJUST THE SCALE FACTOR AND FREQUENCY RESPONSE OF THE CONVERTER 100 VOLT RANGE:

(a) Apply to the converter input terminals a stable, 200 cps ±10%, AC voltage which is lower than 9.550 volts RMS and preferably sinusoidal in waveform. Switch the AC voltage range selector until the digital voltmeter reading just changes to 9.550.

(b) Switch the converter AC voltage range selector switch to the 100 volt range and adjust R3 (the 100 volt calibration adjustment) until the digital voltmeter reads less than the "correct value," and slowly adjust R3 until the reading just changes to the "correct value." The "correct value" is the reading obtained in step 2(a)(3) with the decimal point moved one place to the right.

(c) Change the AC input frequency to 10,000 cps (+0%, -10%) and switch the converter back to the 10 volt range. Starting with the AC input voltages less than 9.550 volts, slowly increase the input voltage until the digital voltmeter just changes to 9.550.

(d) Switch the converter to the 100 volt range. Adjust C6 (100 volt trimmer) for a digital voltmeter reading of less than the "correct value," then slowly rotate C6 until the reading just changes to the "correct value." The "correct value" is the reading obtained in step 2(b)(3) with the decimal point moved one place to the right.

(e) Repeat steps 3(a) and 3(b), readjusting R3 only if, in step 3(b), the digital voltmeter does not read the "correct value" before adjusting R3. If R3 is readjusted, repeat steps 3(c), 3(d), and 3(e).

4. TO ADJUST THE SCALE FACTOR AND FREQUENCY RESPONSE OF THE CONVERTER 1000 VOLT RANGE:

(a) Switch the converter AC voltage range selector switch to the 100 volt range. Apply to the converter input terminals a stable, 200 cps ±10%, AC voltage which is lower than 95.50 volts RMS, and preferably sinusoidal in waveform. Slowly increase the input voltage until the digital voltmeter reading just changes to 95.50.

(b) Switch the converter AC voltage range selector switch to the 1000 volt range. Adjust R5 (the 1000 volt calibration adjustment) for a digital voltmeter reading less than the "correct value", slowly adjust R5 until the reading just changes to the "correct value." The "correct value" is the reading obtained in step 2(a)(3) with the decimal point moved two places to the right.

(c) Change the AC input frequency to 10,000 cps (+0%, -10%) and switch the converter back to the 100 volt range. Starting with the AC input voltage less than 95.50 volts, slowly increase the input voltage until the digital voltmeter reading just changes to 95.50.

(d) Switch the converter to the 1000 volt range. Adjust C5 (1000 volt trimmer) for a digital voltmeter reading of less than the "correct value," then slowly rotate C5 until the reading just changes to the "correct value." The "correct value" is the reading obtained in step 2(b)(3) with the decimal point moved two places to the right.

(e) Repeat steps 4(a) and 4(b), readjusting R5 only if in step 4(b) the digital voltmeter does not read the "correct value" before adjusting R5. If R5 is readjusted, repeat steps 4(c), 4(d), and 4(e).

5.4 MAINTENANCE AND TROUBLESHOOTING.

A. GENERAL: Maintenance personnel must be thoroughly familiar with the physical make-up, specifications, installation and operating procedures, and detailed theory of operation of the digital voltmeter. The first step in correcting any trouble which may develop is to isolate that section of the circuit which is causing trouble. Improper operation of the digital voltmeter usually shows up as improper readout display, whether in a transitory or stabilized condition. Detailed examination of the readout display will almost invariably provide an indication to the probable source of trouble (see the troubleshooting charts in this section).

B. TEST EQUIPMENT: No special equipment is required for normal maintenance of NLS instruments. An ordinary oscilloscope is helpful in tracing amplifier output pulses. Resistance and voltage measurements, both AC and DC, can be made with a multimeter or VTVM, depending on circuit loading considerations.

C. REPLACEMENT OF COMPONENTS: NLS can supply electronic replacement parts at current net prices plus a handling charge. However, since most of the components are standard electronic and radio parts, we suggest you purchase them from your local dealer, if you can. NLS manufactures most of the mechanical parts and some of the components used in the instruments. When ordering a mechanical part, be sure to describe the part completely; also, furnish the model and serial numbers of the instrument to which the part is to be fitted. Contact our nearest Field Engineer or Representative if you have questions about replacement parts. Parts information may also be obtained by writing to the Service Department at our factory in Del Mar, California.

D. DC DIGITAL VOLTMETER MAINTENANCE & TROUBLESHOOTING: The DC digital voltmeter consists of the following main assemblies: (1) error amplifier; (2) power supply; and (3) stepping switch, including readout. Operational adjustments for these items have been described in the paragraphs relating to the adjustment, calibration and test.

1. ERROR AMPLIFIER: The amplifier compares the unknown input voltage with the known feedback voltage from the stepping switch assembly. Whenever these two voltages are unequal, a square wave error signal is generated by the chopper. This signal is amplified; and may be observed by connecting an oscilloscope between ground and either one of the two error signal test points on the error amplifier, in the plate circuit of the phase inverter stage vacuum tubes. When the digital voltmeter is at a balance, the error signal becomes a straight line, modified somewhat by hum and noise pickup. If no error signal is observed at the test points, trace back through the preceding stages to the output of the chopper, until the

error signal once more becomes evident. If necessary, faulty components or tubes should be replaced to regain signal at the amplifiers test points. Existence of 'up" or "down" pulses, generated by the type 5696 thyratrons in the amplifier, can be determined by observing which of the NE2 neon bulbs, on the amplifier, are glowing. Look at the amplifier in its normal mounting position; when a "+" polarity sign is displayed in the readout: (1) "up" pulses are being generated if the lower NE2 neon bulb is glowing; (2) "down" pulses are being generated if the upper neon bulb is glowing. These pulses at the output of the error amplifier take the configuration shown in Fig. 5-4(a).

2. POWER SUPPLY CHASSIS: The power supply in the DC digital voltmeter furnishes B^+, B-, amplifier filament power, and power for the readout lamps. A thermal time delay relay withholds plate voltages from the type 2D21 thyratrons ("power thyratrons") in the power supply, until the filaments are fully heated. The amplifier output pulses, described above, are furnished to the power supply where they trigger one of the two type 2D21 thyratrons. These pulses from the power supply are routed to the logical switching circuits in the stepping switch assembly. If the stepping switch circuit is open and the switches do not step, the pulses from the power thyratrons on the power supply chassis will resemble Fig. 5-4(B) on an oscilloscope screen. The pulse waveform across the coil of a normally operating stepping switch will resemble Fig. 5-4(c) on an oscilloscope screen.

3. STEPPING SWITCH ASSEMBLY.

   (a) Stepping Switch Lubrication - The components of the stepping switch assembly are mounted on a substructure attached to an epoxy-fiberglass etched circuit board. The substructure and associated components are inside the stepping switch tank when the etched circuit board is in position on top of the tank.

   The stepping switch tank contains one quart of lubricating and dielectric oil, especially compounded by NLS, to extend the life of the mechanical parts and the electrical contacts of the stepping switches. Instruments which are not operated in a level position, such as in consoles having inclined panels, should be removed from their normal locations at intervals of approximately three months. The complete instrument should then be tilted back and forth several times, or operated in a level position, to make sure that the lubricating oil in the tank coats each switch.

In some early NLS five digit instruments, a single stepping switch, for polarity control, was mounted on top of the epoxy-fiberglass etched circuit board which forms the top of the stepping switch tank. This switch, since it is not contained in the oil bath, must be manually lubricated every three months. To lubricate most points, a #4 Artist's Sable Rigger Brush is used. A "dip" is the amount of lubricant retained on the brush when it is dipped 3/8" into the lubricant and lightly scraped on the edge of the container to remove the excess oil. To lubricate the polarity switch described above, use the procedure described in Table 5-2.

No adjustment of a stepping switch is required until the switch has made one-half million revolutions, or the switching becomes erratic. Refer to Figure 5-6 to become familiar with the proper names of the different parts of the stepping switch.

TABLE 5-2 LUBRICATION CHART FOR ANY STEPPING SWITCH NOT IN AN OIL BATH.

LUBRICATION POINT	TYPE LUBRICANT	LUBRICATION PROCEDURE
Wiper assembly bearing	Clock oil or equivalent	Apply one dip near the pointer
Each pair of wiper contacts	Clock oil or equivalent	Draw a strip of bond paper, treated with two dips on each side, through the wiper contacts. Rotate assembly to distribute lubricant.
Inner sides of each pair of wipers where brush springs ride	Clock oil or equivalent	Apply one dip of oil at the points indicated
Armature bearing	Light mineral oil	Apply one dip to each side of bearing.
Pawl bearing	Light mineral oil	Apply one dip to each side of bearing.
Pawl spring hooks	Light mineral oil	Apply one lean drop to the hooks at the eyelets.
Ratchet teeth	50-50 mixture (by volume) of powdered mica and clock oil	Apply two dips to the ratchet teeth, rotating to distribute lubricant.

(b) Stepping Switch Adjustment - Generally, a stepping switch requires adjusting only if it has been disassembled; or parts have been replaced; or erratic stepping action has been traced to the switch.

To adjust a stepping switch, follow the procedure outlined below:

(1) Inspect switch for cleanness, and check for mechanical damage. Clean or repair as required.

(2) Insert a #42 drill shank into hole in wipers. The drill should penetrate all wipers and must be parallel with axis of wiper assembly. If required, remove and re-align rotor assembly then re-install.

(3) Loosen the contact bank assembly mounting screws and position the contact bank assembly so the wiper tip contact area is in the center of the stationary contact. Rotate the stepping switch manually. Wiper tips should touch the same point on all stationary contacts.

(4) Adjust the contact bank assembly so the trailing edge of the wiper tip is even with the stationary contact edge to give full contact area. Tighten the contact assembly mounting screws. Manually operate the stepping switch and check operations performed in steps 3 and 4.

(5) Loosen the armature bearing and armature backstop adjustments. Place a .010 inch feeler gage between the bearing end of the armature and the heelpiece. Firmly press the armature against the heelpiece and tighten the armature adjustment nut.

(6) Place .050 inch feeler gage between armature (pawl end) and heelpiece. Firmly press armature backstop against armature and tighten armature backstop adjustment screws.

(7) Loosen pawl stop adjustment screws. Position the pawl stop to be parallel with and lightly touching the pawl. Tighten screws and check the pawl stop alignment with the pawl.

(8) Place .001 inch feeler gage between the armature and armature backstop. Pull out feeler gage. The gage will drag upon withdrawal. If drag is too light, indicating lack of pressure, or too heavy, indicating lack of clearance, repeat steps 5 and 7 as required.

(9) Loosen detent adjustment screws. Position detent spring so it is aligned with the rachet and does not interfere with the wipers. Lightly, tighten screws. Place .001 inch feeler gage between end of detent spring and rachet. Adjust detent spring to press lightly against feeler gage, and tighten screws. The gage will drag upon withdrawal. Manually operate armature. Detent spring must engage rachet.

(c) Digital Readout Maintenance - The only maintenance step normally required for the digital readout is lamp bulb replacement. However, if readout plates require cleaning because of subjection to extremely adverse dust or humidity conditions, clean them with commercial isopropyl alcohol and lint free paper, such as KIMWIPES 900-L, manufactured by Kimberly Clark, Neenoh, Wisconsin. Readout plates can be slid from their grooves after removing either structural end plate from the readout. Readout plate and bulb placement is shown in Fig. 5-8. However, to avoid any possible error, record the location of each readout plate as it is removed. As the readout is reassembled, avoid reversing or inverting the readout plates, particularly 1, 0, 6, 8, and 9. The engraved side of the readout plates should face the rear of the readout. Avoid scratching the readout plates and polaroid filter. Also, if the polaroid filter is removed, it must be reinstalled with the proper side inward. Hold a piece of shiny metal against the filter sheet and look through at the metal. Turn the filter over and again look through at the metal. The correct side of the filter to face the rear of the readout is that which was in contact with the metal when the least glare was observed from the metal surface.

To replace burned-out lamps in the digital readout, proceed as follows:

(1) Remove the escutcheon plate around the readout by removing the Phillips-head screws which secure it to the front panel.

(2) The left and right ends of the readout assembly are secured to a guidepost by an Allen-head set screw. Support the readout assembly with one hand; and loosen the Allen-head set screws with a suitable wrench, until the readout assembly slides down and the readout lamps are exposed.

CAUTION: The pressure of the springs which hold each readout lamp in contact with its associated terminal is great; therefore, it is necessary to provide sufficient support for the readout while the Allen-set screws are being removed. If sufficient support is not provided, the springs will cause the readout to drop; and this, in turn, will cause the readout bulbs to jump out of position.

(3) Readout lamps can now be removed and replaced. Since electrical contact is maintained by spring force, soldering of wires is not required. However, a bead of solder placed

on the center contact of replacement lamps ensures good electrical contact.

G.E. Type 328 Aviation Instrument Lamps are generally used in the readouts which are installed in NLS digital instruments. Other G. E. Aviation Lamp types have been used in special cases:

TYPE	VOLTAGE	CURRENT
328	6	0.2 amp.
330	14	0.08 amp.
327	28	0.04 amp.

(d) Kelvin Varley Voltage Divider - Any deficiencies which develop in the Kelvin-Varley voltage divider should become evident during a linearity test. However, most types of deficiencies will appear during normal use of the instrument, or during a test wherein the input voltage is slowly varied from zero to full scale on the instrument's lowest range (observing the error amplifier waveform during such a test is helpful). Some deficiencies are described below:

(1) If the instrument either oscillates at some point in its range, or reads all nines, look for open circuited resistors, broken wires, or stepping contact failure.

(2) If, as the input voltage is slowly increased, the readout display skips a number, it is probable that a resistor associated with the old and new displayed numbers is too low in ohmic value.

NOTE: Normal automatic gain control operation can cause the skipping of numbers on parts of the range (if any) where the gain control operates.

4. REFERENCE VOLTAGE SOURCE TROUBLESHOOTING: As explained in Section 4, the reference voltage source main requirements are correct amplitude, sufficiently low electrical noise and ripple in the output, and adequate stability.

(a) Zener Diode Type - This reference supply has very few components, and is normally troublefree. Therefore, no trouble chart or service information other than that given below is presented.

Make certain that the red dot end of the Zener diodes is connected to the positive output lead, and that matched temperature compensated pairs of Zener diodes are used for replacement. Do not disturb the phase relationship of the power cord with the digital voltmeter power cord; unstable digital readout or disagreement of + and - readings can result.

(b) Autocalibrator - A good starting point in autocalibrator troubleshooting is to turn the autocalibrator's output voltage control from one end to another, and observe the output voltage change. If only a slight voltage change is observed (less than 0.1%), then the correction amplifier (stages V1-A, V1-B, and V2-A) is defective. If the correction amplifier is defective, then the best procedure is to start at the amplifier output transformer secondary winding and work through the amplifier (towards the standard cell) with an oscilloscope, to determine where the square wave error signal was lost. A high gain

oscilloscope will be required when working at the correction amplifier input.

If the correction amplifier seems to be functioning but the output voltage is still wrong, it is advisable to check the voltage at the amplifier output transformer center tap. If this voltage is not approximately equal to the nominally correct output voltage of the autocalibrator, then measure the voltage across the associated gas regulator tube. If this voltage is improper, replace the gas tube and/or check the power supply.

When the autocalibrator is operating properly, the feedback voltage (from V2-B cathode circuit to the chopper pin 3) should equal the standard cell voltage. If this is true, and the output voltage is incorrect, then there is trouble in V2-B cathode circuit; for example, the cathode resistors may have changed value. To check the equality of voltage at chopper pin 3 and the standard cell voltage, (1) use a digital voltmeter; or (2) measure the standard cell approximate voltage with a VTVM, and then check the voltage at chopper pin 2 with a high gain oscilloscope.

If the autocalibrator output voltage drifts, suspect low gain in the correction amplifier.

If the autocalibrator output voltage is too low, check the standard cell voltage and replace the standard cell if necessary.

If the standard cells are replaced, standardize the autocalibrator per Section 5-2(c).

CAUTION: The chopper is specially adjusted at NLS. For best results, obtain replacement choppers from NLS. The main requirements are that the chopper be adjusted for break-before-make operation (to prevent standard cell damage), and that the switch section associated with the output stage close about 10 degrees after the other section closes, and open about 10 degrees before, thus avoiding demodulating the transient created when the section associated with the input stage is in motion.

(c) Replacing Standard Cells. (Also see Section 5-2(c))

Three Digit Instruments - Most three digit instruments have a standard cell voltage divider incorporated as shown in Fig. 5-2, although some do not. Consult your Circuit Schematic.)

When replacing standard cells in three digit instruments having a standard cell voltage divider, calculate the new, correct standardization numerical display, E_o, from the formula: $E_o = E_s \left(\frac{R1}{R1+R2}\right)$. (See Fig. 5-2 for a definition of the formula symbols).

For instruments which do not have a standard cell voltage divider, the correct standardization numerical display is the same as the standard cell emf.

Four and Five Digit Instruments - The circuitry relating to establishing the correct standardization numerical display in four digit instruments is shown in Figure 5-3. Five digit instruments are the same except for the exact make-up of R2. For this circuit, the correct standardization numerical display, E_o, is calculated using the formula: $E_o = E_s\left(1+\frac{R1}{R1+R2}\right)$.

As the formula and Figure 5-3 indicate, the voltage drop in the input signal, caused by the voltage divider formed by the DC resistance of the input filter choke and the range attenuator total resistance, is compensated for by the above formula.

E. AC TO DC CONVERTER TROUBLESHOOTING. (Not applicable to schematics dated prior to 1/9/58).

In the following, it is assumed that the DC digital voltmeter connected to the AC to DC converter output is functioning properly. Many trouble symptoms of AC-DC digital voltmeters are traceable to the DC digital voltmeter. Before troubleshooting the AC to DC converter, one should be thoroughly familiar with the precautions listed in the early paragraph of Section 5-3, AC to DC Converter Adjustments. A chart of typical DC voltages is given on a following page. If any components are replaced, it is advisable to recheck the AC to DC converter calibration.

The most frequent symptoms of trouble in the AC to DC converter are a "high" reading (more than three digits) when the input terminals are shorted together (this is called "Zero offset"), amplitude non-linearity, frequency non-linearity, and the necessity of adjusting C16 during the calibration procedure of Section 5-3. The most frequent causes of trouble are faulty vacuum tubes, faulty diodes, and other defective components, in that order. Therefore, the first attempt to remedy trouble should be to replace vacuum tubes and next, the diodes.

The characteristics of V3 and V4 are important; one should try interchanging V3 and V4, and/or try a number of replacements in each socket, before deciding that V3 and V4 are not at fault. A plate voltage lower than 90 volts on V4 (pin 8) usually indicates that V3 and/or V4 should be replaced.

A clue, although not always a reliable one, to faulty diodes is the waveform across each diode load resistor (R35 and R36). To check this, apply a 9.5 volt, 10 KC, sinusoidal input to the converter. Next, connect an oscilloscope which has good frequency response to 100 KC across R35 and then across R36. If across either R35 or R36 the overshoot (B), indicated in the waveform below exceeds 8% of the amplitude, (A), then the associated diode is probably faulty.

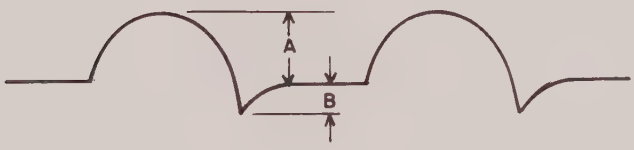
If the "converter section" of the unit is good, the DC output voltage will, unless V5 has failed, be between 0.025 and 0.050 volts when V3 pin 1 is connected to signal ground. A zero offset of one digit in the digital instrument occurs for approximately each 0.030 volts measured in this test.

A quick check on the unity gain amplifier, V1 and V2, is to measure its output (V1 Pin 7) when about 9.5 volts RMS is applied to the converter

input with the converter on its 10 volt range. The output should be equal to the input. Use a VTVM with an isolation resistor in its probe because excessive capacitance from V1 pin 7 to ground will cause oscillation.

Zero offset is frequently caused by low loop gain in the converter section. This is usually attributable to faulty tubes V3, V4, or V5.

When working on or replacing the range selector switch, re-establish the original location of wiring in the switch sections associated with the range attenuator resistors, which are the foremost sections of the switch. Wiring capacitances are critical throughout the range attenuator circuitry.



TYPICAL DC VOLTAGES IN AC TO DC CONVERTER
(Measured with 10 megohm input impedance digital voltmeter or VTVM)

LOCATION	TYPICAL VOLTAGE RANGE
V1 Pin 7	41-53
V1 Pin 5	150-160
V1 Pin 6	150-160
V2 Pin 3	4.1-4.5
V2 Pin 1	90-110
V2 Pin 6	222-233
V3 Pin 3	1.17-1.4
V3 Pin 7	31-36
V3 Pin 8	275-285
V4 Pin 8	90-120
V5 Pin 7	149-173
V5 Pin 1	2.15-2.3
V7 Pin 5	479-495
Output Terminals	0.025-0.050 with V3 Pin 1 connected to signal ground.
Junction of R46 & R48	168-174
Junction of R48 & R49	82-86.5

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER

TROUBLE	PROBABLE CAUSE	REMEDY
Entire visual readout fails to light up	Power switch in off position	Turn on power switch.
	No 110V ac line voltage	Trace line failure.
	Power cable defective	Repair or replace cable.
	Fuse blown	Replace fuse.
	No 6V AC	Check for 6V AC at various points.
	Power transformer open circuited	Replace power transformer.
Some characters in the visual readout display fail to light up	Defective readout indicator lamp	Replace lamp.
	No 6V AC available at center contact of lamp	Trace 6V AC line through associated stepping switch.
Unstable readout display	Amplifier gain too high	Adjust amplifier gain.
	Excessive ripple on unknown DC input voltage	Provide suitable filter between unknown voltage source & digital voltmeter leads.
	Stray noise voltage being picked up	Connect chassis of digital voltmeter to good earth ground. Use shielded leads. Reverse two-pronged 110V AC power plug. Readjust hum control.
	Microphonic or gassy 5751 (1st stage amplifier)tube	Replace 5751 tube.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER (CONTINUED)

TROUBLE	PROBABLE CAUSE	REMEDY
Unstable readout display	Unstable 5696 thyratron in amplifier	Replace 5696 tubes.
	Faulty reference voltage circuit connections	Check connections.
	Decade stepping switch contacts making intermittent contact	Increase wiper tension.
	Reference voltage supply noisy or not regulating	See section of text dealing with reference supplies.
	Noisy or partially shorted resistors in range attenuator or Kelvin-Varley divider	Replace faulty resistors.
	Faulty ground circuit connection inside instrument	Find and repair faulty connection.
Readout display decreases in steps of more than one digit when input voltage is decreased very slowly below 10% of full scale in five digit, or anywhere in three and four digit instruments.	Low Amplifier gain	Adjust amplifier gain.
	Low Amplifier gain	Check amplifier tubes & replace any found to be weak or defective.
	Amplifier saturated with noise	Observe effective shielding and grounding procedures.
		Adjust hum control.
		Replace amplifier tubes.
	Reference voltage low	Increase reference voltage.

F. TROUBLESHOOTING CHART DC DIGITAL INSTRUMENT (CONTINUED)

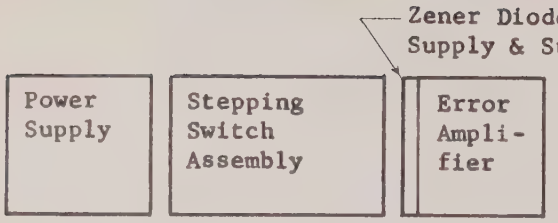
TROUBLE	PROBABLE CAUSE	REMEDY
Visual readout display increases and stays at full scale when input voltage is less than full scale.	Feedback voltage missing at chopper	Re-establish continuity of reference voltage circuit.
	Reference source connection incorrect (external reference instruments)	Connect reference source correctly.
	Defective chopper	Replace chopper.
Readout display will not increase.	No error signal	Replace chopper.
		Make point-to-point check of amplifier with oscilloscope.
	"Up" pulses missing	Check range attenuator output voltage line from range stepping switch to pin 4 of chopper.
		Replace type 5696 tube in amplifier and 2D21 in power supply.
		Replace defective neon tube in amplifier assembly.
		Check feedback voltage line from decade one switch to chopper.
	Low line voltage (Less than 105V AC)	Remedy cause of low line voltage or employ a step up transformer.
Readout display will not decrease.	No error signal	Replace chopper.
		Make point-to-point check of amplifier with oscilloscope.
	Low line voltage	Correct cause of low line voltage.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER (CONTINUED)

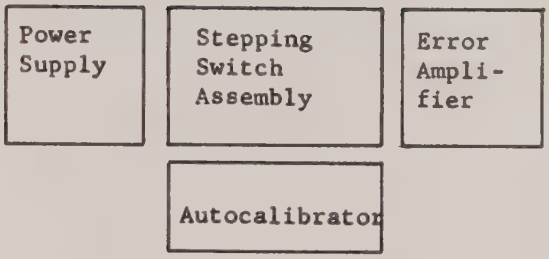
TROUBLE	PROBABLE CAUSE	REMEDY
Readout display will not decrease.	"Down"pulses missing	Check feedback voltage line from decade one switch to chopper.
		Replace type 5696 tube in amplifier and 2D21 in power supply.
		Replace defective neon tube in amplifier.
		Check range attenuator voltage line from range stepping switch to chopper.
Readout display will neither increase nor decrease.	Selector switch in "STANDBY" position	Turn selector switch to "ON" position.
	Time delay relay tube in power supply not functioning	Replace time delay tube in power supply.
	No "up" or "down" pulses available at stepping switch coils	Repair pulse lines from amplifier to power supply or from power supply to stepping switch assembly.
	Defective thyratrons in amplifier or power supply	Replace 5696 tube and 2D21 thyratrons.
	No error Signal	Trace error signal from chopper thru amplifier. Correct reason for loss of signal.
		Replace Chopper.
		Establish unknown input signal or feedback voltage at chopper.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER (CONTINUED)

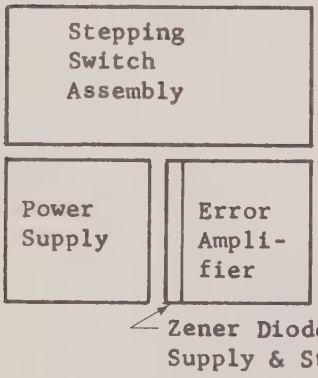
TROUBLE	PROBABLE CAUSE	REMEDY
Readout display will neither increase nor decrease.	Amplifier saturated with noise	Observe effective shielding and grounding procedures.
		Adjust hum control.
		Replace amplifier tubes.
When input signal polarity is reversed, numerical reading differs by more than accuracy specification will permit.	See listings under "Unstable readout display": input ripple, stray noise, faulty 5751 or 5696 tubes, stepping switch wiper tension low, reference voltage faults, noisy resistor, faulty ground circuits in instruments.	See associated remedies under "Unstable readout display."
	Input signal DC amplitude actually changes when leads to instrument are reversed.	If differing readings are construed as "trouble," and not "desired data," then signal source may be at fault.
	Amplifier gain low	Readjust gain control.
	Reference voltage low	Increase reference voltage to proper value.



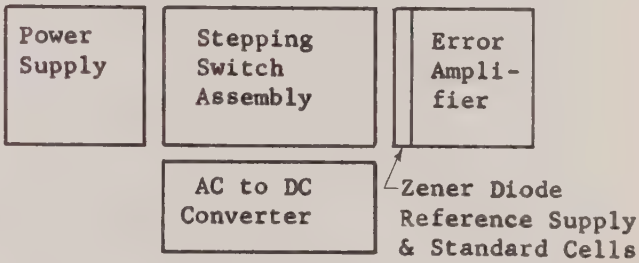
DC Digital Voltmeter, Rack mount style, manually calibrated.

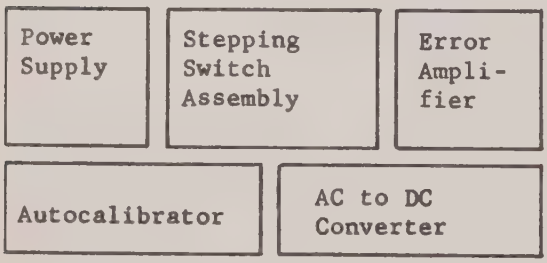


DC Digital Voltmeter, Automatically calibrated.



DC Digital Voltmeter, Bench Style, manually calibrated.





AC - DC Digital Voltmeter, Automatically calibrated.

NOTE: Print control, when included, is located on power supply chassis.

FIGURE 5-1 ARRANGEMENT OF DIGITAL VOLTMETER SUBASSEMBLIES VIEWED FROM FRONT OF INSTRUMENT

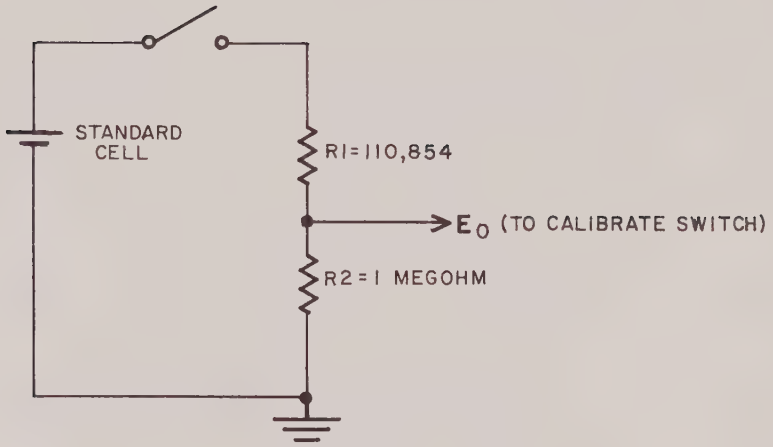


FIGURE 5-2. STANDARD CELL VOLTAGE DIVIDER AS INSTALLED IN MOST 3 DIGIT INSTRUMENTS.

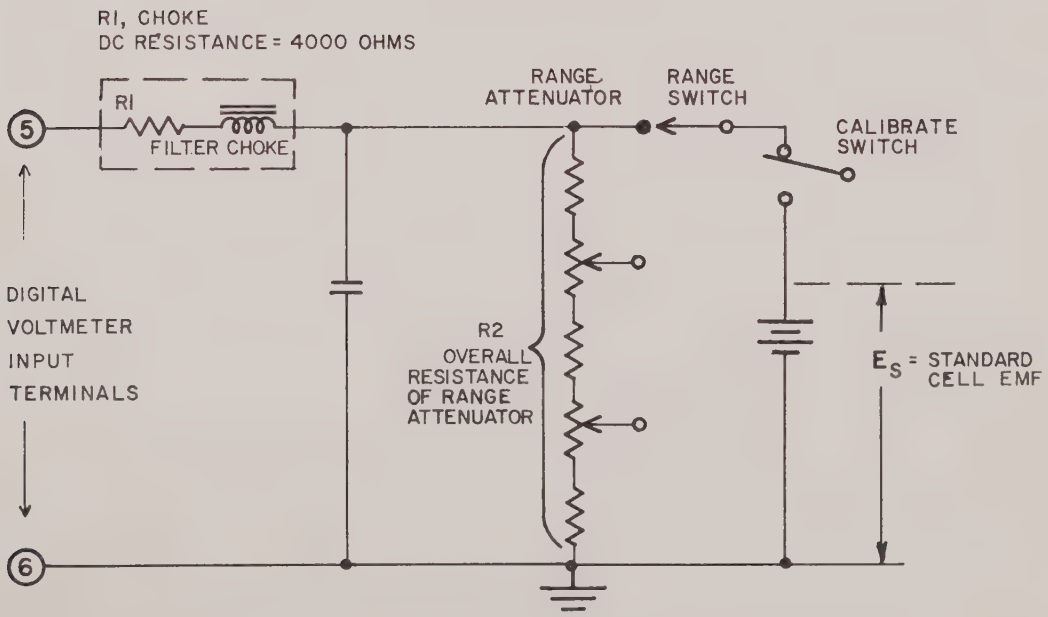


FIGURE 5-3. CIRCUITRY RELATIVE TO STANDARDIZING FOUR AND FIVE DIGIT INSTRUMENTS.

(A)

"UP" AND "DOWN" PULSES AT ERROR AMPLIFIER OUTPUT TERMINALS.

(B)

POWER THYRATRON OUTPUT PULSES WHEN STEPPING SWITCH COIL CIRCUIT IS OPEN CIRCUITED.

(C)

PULSE ACROSS STEPPING SWITCH COIL

FIGURE 5-4. TYPICAL PULSE WAVEFORMS.

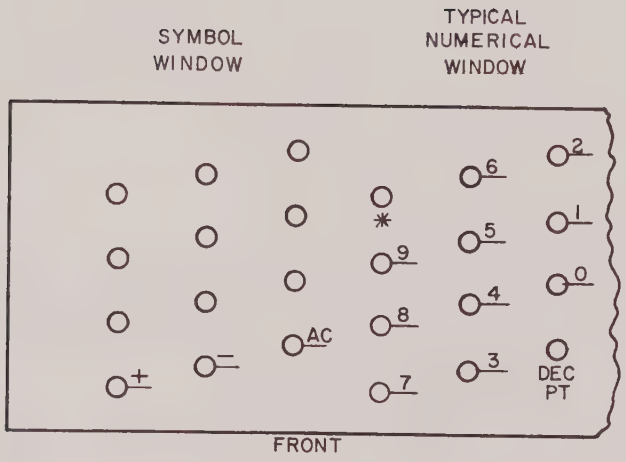


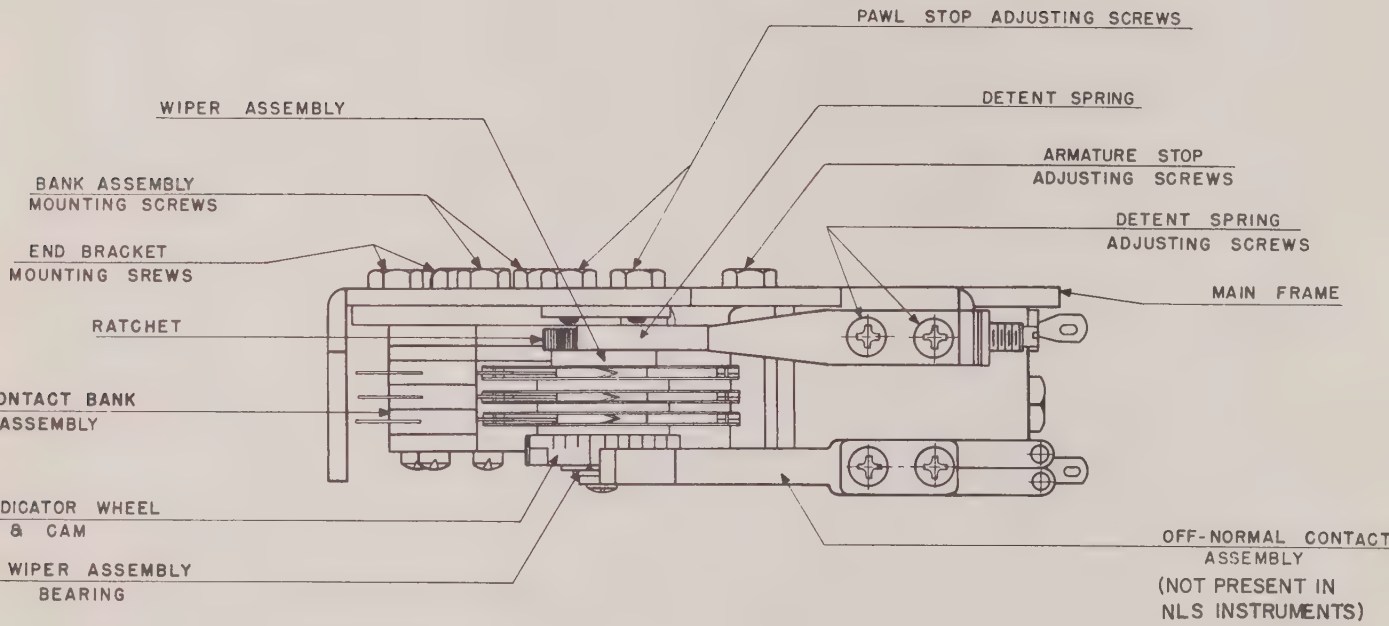
FIGURE 5-5. ARRANGEMENT OF READOUT BULBS AND PLATES (TOP VIEW)

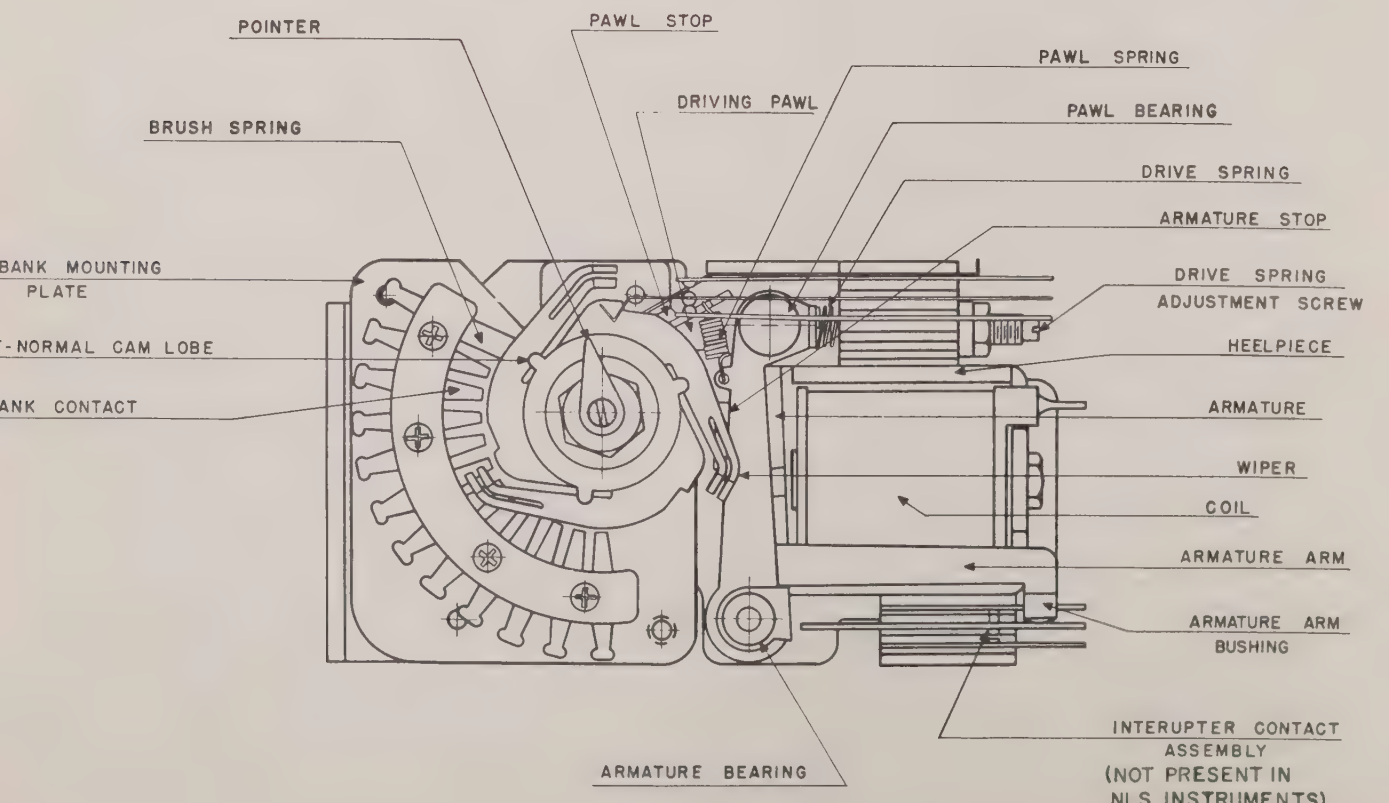
* OVERLOAD INDICATION FOR AC RANGES

FIGURE 5-6

TYPE II SWITCH

IDENTIFICATION OF PRINCIPAL PARTS





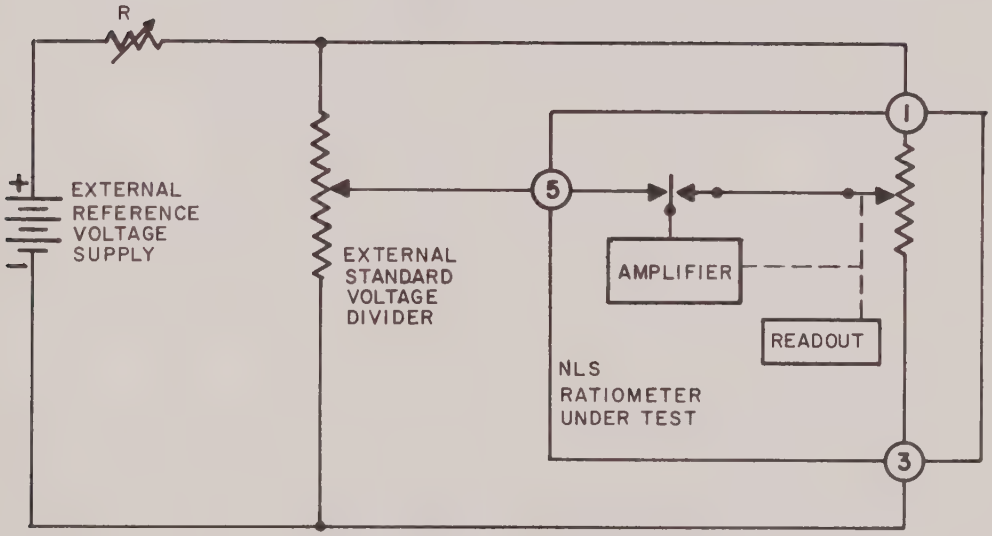


FIGURE 5-7A. TEST SETUP FOR DECADE LINEARITY TEST OF NLS RATIOMETER BY THE RATIOMETER METHOD

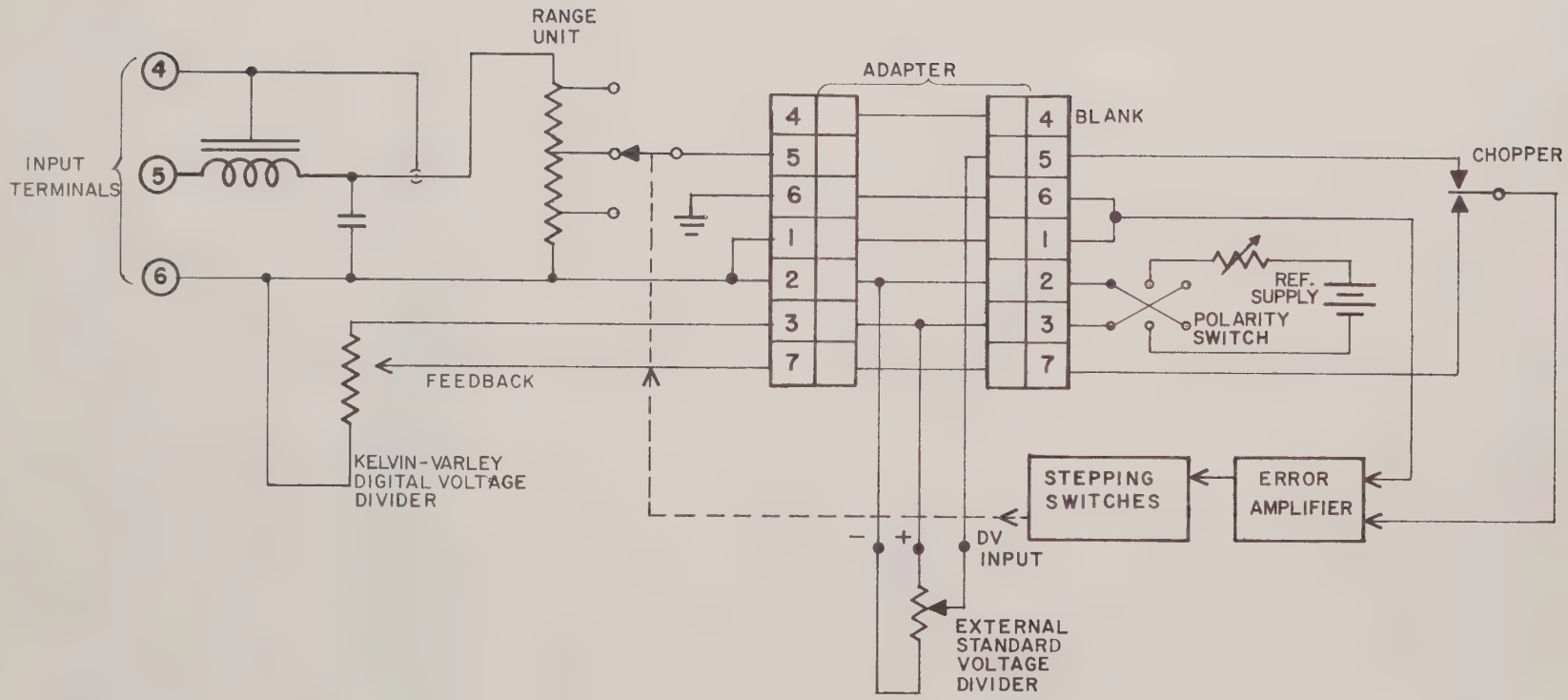
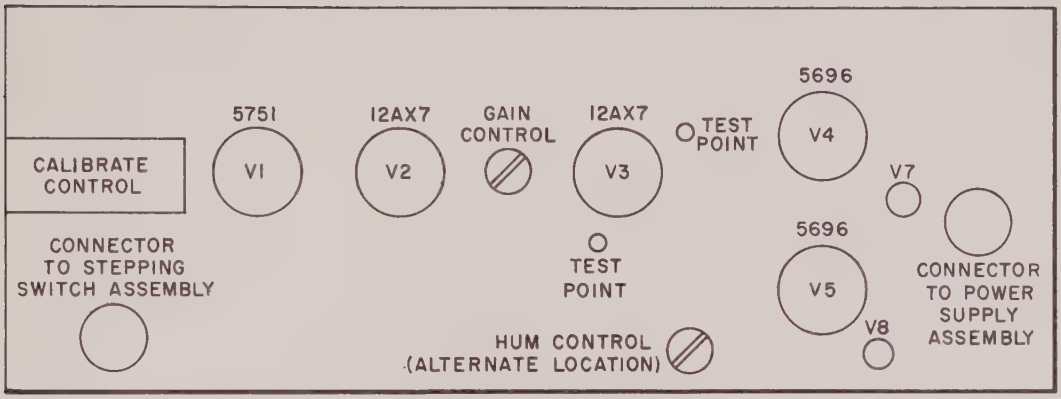
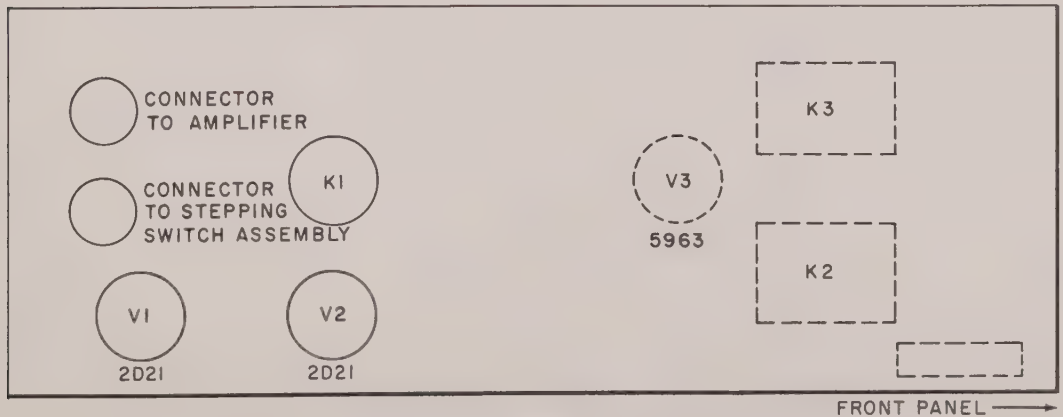


FIGURE 5-7B. TEST SETUP FOR DECADE LINEARITY TEST OF TYPICAL DIGITAL VOLTMETER, SHOWING USE OF ADAPTER PLUG TO FACILITATE CONNECTIONS OF VOLTAGE DIVIDER.



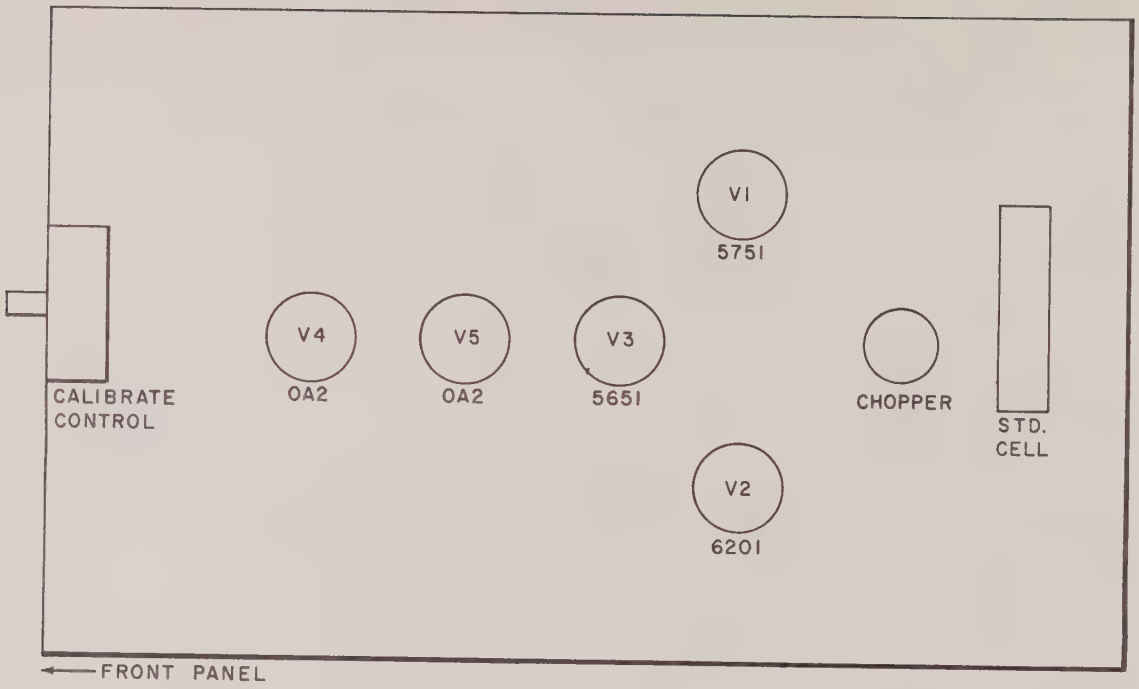
ERROR AMPLIFIER

POWER SUPPLY (OLDER DESIGN)

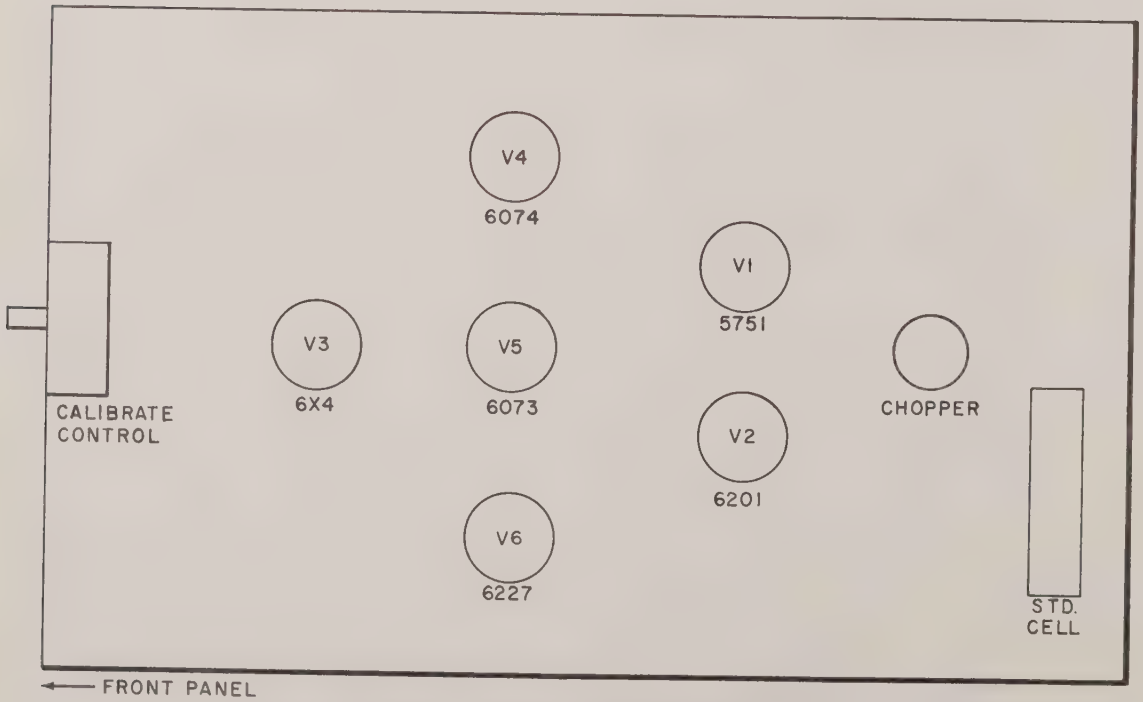


POWER SUPPLY (NEWER DESIGN) PRINT
CONTROL COMPONENTS SHOWN DOTTED

FIGURE 5-8 COMPONENT LOCATION, ERROR AMPLIFIER AND POWER SUPPLY

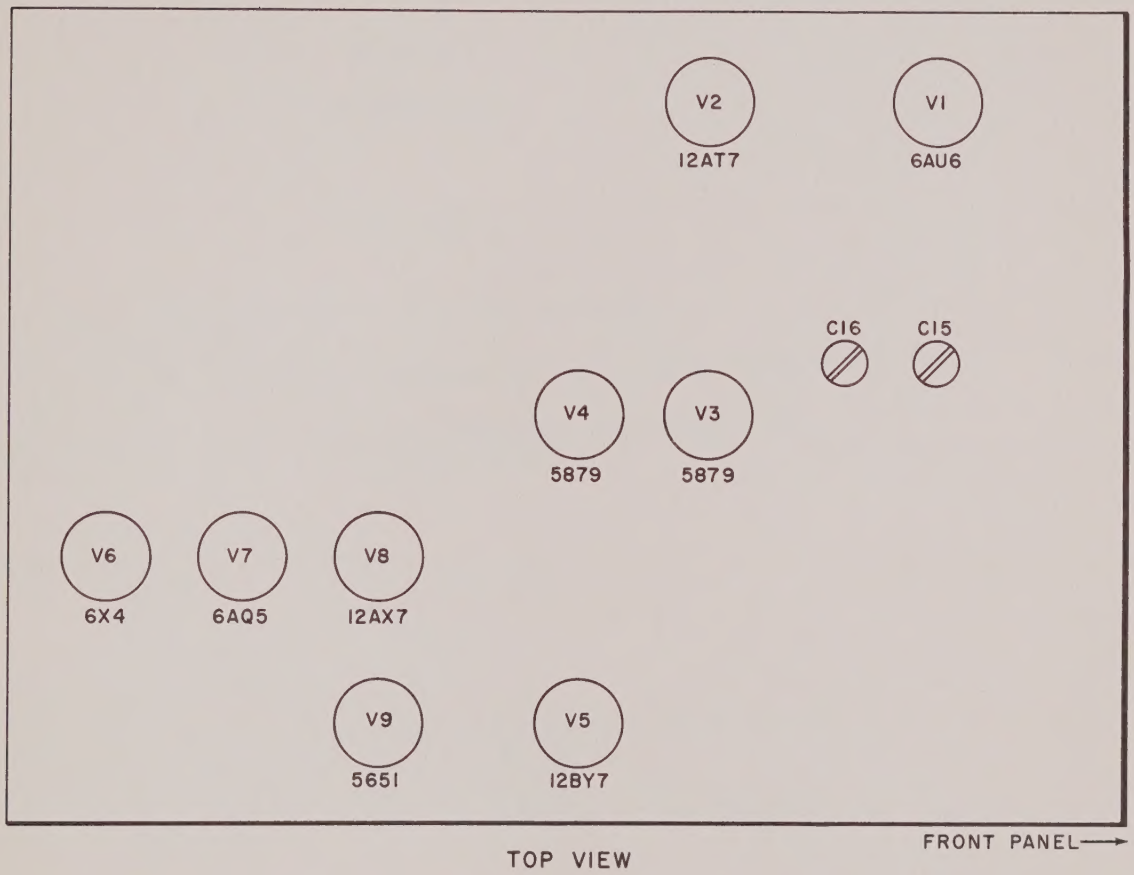


FOR 3 AND 4 DIGIT INSTRUMENTS

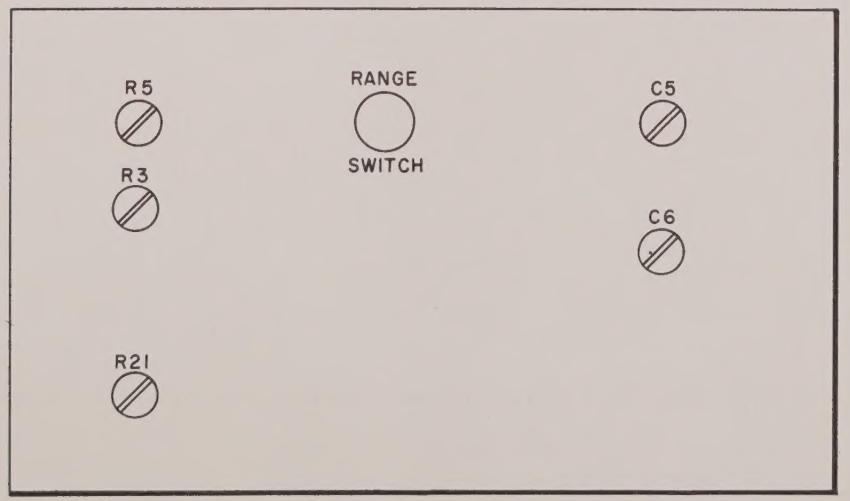


FOR 5 DIGIT INSTRUMENTS

FIGURE 5-9 AUTOCALIBRATOR COMPONENT LOCATION



TOP VIEW



FRONT VIEW

FIGURE 5-10 AC-DC CONVERTER COMPONENT LOCATION

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